DISTRIBUTION OF FISH AND TEMPERATURE PREFERENCE OF YELLOW PERCH IN THE THERMAL PLUME OF A POWER PLANT AS DETERMINED BY RADIO TELEMETRY

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Abstract

The movement patterns of four fish species, yellow perch (Perca flavescens), northern pike (Esox lucius), largemouth bass (Micropterus salmoides) and walleye (Stizostedion vitreum) were monitored with radio telemetry methods near the thermal discharge of a power plant, (Δ T 15°C nominal). A minature temperature sensing transmitter and an automatic recording system were developed for use with yellow perch. Fish movements relative to depth, temperature, center of the home range, discharge point, and release location are examined. Near thermally altered areas northern pike exhibited the greatest amount of movement followed by yellow perch, walleye and largemouth bass. Except for largemouth bass, thermal experience was found to be transitory. An overall winter temperature preference of 5.4°C was determined for yellow perch. I concluded that temperature, when in concert with numerous other environmental variables, did not alter the distribution of yellow perch to that predicted on the basis of laboratory temperature preference studies.

ACKNOWLEDGEMENTS

I would like to express my appreciation to my parents for instilling an awareness of the beauty of nature through the numerous pleasant experiences enjoyed on hunting and fishing trips. I am also gratefull to Tom Moore for introducing me to the refreshing experience of living and working in Northern Minnesota. I owe special thanks to Dr. James C. Underhill who directed and encouraged an early interest in aquatic biology to the areas of ichthyology and field biology.

I am gratefull to all those who made this project possible and assisted on various portions. Electronic equipment was designed and constructed by Larry Kuechle, Dick Reichle and Ralph Schuster of the Cedar Creek Bioelectronics Laboratory. Todd Montgomery, Peter Alexander, Steve Kalkoff and Marv Granroth assisted with field work. Jeff Malmgren and Gary Erickson provided 'moral' support. Kathlean Zinnel designed computer portions of the data analysis and offered needed statistical advice. Tom Lanwehr and Denise Stinson transcribed field data to computer format. Bev Bonde and Kris Kohn drew many of the original figures.

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INTRODUCTION

Addition of heated water to the environment alters a major physical component of the aquatic ecosystem. Temperature has a fundamental effect on all life functions. In general, increased temperatures accelerate biochemical reactions; an approximate quantification is given by Van't Hoff's generalization which states that the speed of most biochemical reactions approximately double for each $10^{\circ}C$ increase in temperature. Effects of temperature on aquatic life have been investigated for many organisms, both in natural conditions and laboratory situations. Books by Gibbons and Sharitz (1974) and Rose (1967) deal with the effects of temperature on living systems. Bibliographies by Beltz et al. (1974), Kennedy and Mihursky (1967), Morgan and Franzreb (1970), and Raney et al. (1973) document the great deal of information available on thermal effects relative to aquatic organisms. Research reviews of thermal effects literature by Coutant (1969, 1970), Coutant and Goodyear (1972), Coutant and Pfuderer (1973, 1974), Holdaway (1967) and Hokanson (1977), summarize research findings of thermal effects on fish. Most aquatic ectotherms are adapted for life in a relatively narrow temperature range. This range varies for individual species depending upon acclimation, season, and life stage. Alterations of normal seasonal temperatures can affect an organism's behavior, survival, growth, and reproduction.

Fish are closely tied to the temperature of their surroundings. As Brett (1956) pointed out, the tissues of fish are constantly being brought to equilibrium with the external environment as the network of the circulatory system is brought into thermal equilibrium with surrounding water at the gill-water interface. Further, the equilibrium state is reached faster in small fishes.

The yellow perch, *Perca flavescens*, has evolved under a north temperate environment. Its native distribution includes the northeast and north central United States and most of central and eastern Canada (Scott and Crossman 1973). Yellow perch are a popular sport and commercial fish in many areas of its range and, perhaps more importantly, this relatively small species is a principal link in the food chain of more sought-after fish such as the walleye, *Stizostedion vitreum*, and northern pike, *Esox lucius* (Dobie 1966, Seaburg and Moyle 1964, and Maloney and Johnson 1955).

Laboratory studies indicated unseasonably warm water could adversely affect the reproductive success of yellow perch. Ferguson (1958) reported that temperature acting alone determined the distribution of fish in a laboratory tank. Further, the final temperature preferendum for yellow perch was 24.2^{o}C in laboratory tanks, and in the 19.7^{o}C to 21.2^{o}C range under natural conditions. McCauley and Read (1973) concluded that age played an important role in temperature selection and pointed out that adult perch temperature selection is approximately 3^{o}C lower than that of juveniles. This observation had previously been noted by Barans and Tubb (1973), who further concluded that temperature selection changed with season. Their studies indicated that adult yellow perch had a winter temperature preference of 12^{o}C to 16^{o}C. This temperature range is considerably above thermal characteristics of north temperate waters under normal winter temperature conditions. DeVlaming (1972) pointed out the potential need for cool temperatures for fish gonad maturation. This hypothesis was examined for perch by Jones et al. (1976) where in it was determined that yellow perch reproductive success, as measured by egg viability, was optimal if the fish had a winter chill period of $4^{\circ}C$ for 185 days. Reproductive success was impaired when winter temperatures increased from $4^{\circ}C$ and as the period at $4^{\circ}C$ became less or greater than 185 days. These studies conducted under laboratory conditions indicated that adult perch can and do select unnaturally high winter temperatures. Furthermore, this selection could lead to a decrease in reproductive success.

With this knowledge, the problem facing aquatic biologists is to determine under field conditions the effect, if any, of thermal effluents on perch populations. Many temperate latitude fishes are attracted to warm water in the winter and cool water during the summer under natural conditions (Bennett 1970). A similar phenomenon has been reported for thermal discharges (Gibbons, et al. 1972, Marcy and Galvin 1973).

A river-lake environment altered by a thermal effluent is a complex thermal situation. Hydrologic models can describe the thermal environment; however, it is subject to variation with changes in power plant operations, weather, season, ambient temperatures, and river flow. In the presence of thermal discharges, fish have an expanded range of temperatures to choose from. The mobility of free-swimming fish combined with the dynamic nature of discharge areas makes physiological studies of captured individuals difficult. Researchers seldom know the thermal history of an individual fish prior to collection. However, biotelemetry offers the opportunity to monitor temperature and location of free-ranging animals within their native habitat.

Biotelemetry was defined by Caceres (1965) simply as "measurement at a distance of quantities having biological interest scientifically or technologically." Fundamentally, biotelemetry involves a sensor-transducer detecting a biological parameter and producing a signal which is transmitted to a receiving-recording apparatus. The first reported successful transmission of biological data from living unanesthetized animals involved measuring pigeon wing-flapping by Marey in 1869 (Fryer et al. 1976).

Advances in radio technology have brought us to the point where many behavioral and physiological parameters can be measured in free ranging animals. Underwater biotelemetry relative to fisheries began in the 1950's (Trefethen 1956). Winter (1976) and Bahr (1977) documented the history and advances in aquatic animal tracking. Initially, ultrasonic telemetry in the 30-3000 Khz. frequency range was developed for aquatic purposes because ultrasonic energy travels well through water and radio frequency signals are attenuated rapidly in salt water. Later, radio frequency telemetry in the 30-164 Mhz. range was adapted from terrestrial wildlife studies for fresh water purposes. Since radio frequency transmitts well through air, it offers two advantages. First, it allows monitoring without physical contact with the water. Second, it offers better transmission through turbulent water and dense aquatic vegetation. Thus, radio frequency biotelemetry is gaining favor among aquatic biologists. Winter et al.

(1978) and Stasko and Pincock (1977) have discussed in detail the advantages and limitations of underwater ultransonic and radio biotelemetry.

Originally, the location of an animal was the major focus of acquatic telemetry research. More recently, fish transmitters capable of monitoring temperature and depth have been developed for acquatic applications. The University of Minnesota Biotelemetry Laboratory has constructed radio frequency temperature and depth transmitters to investigate the behavior of fish relative to such environmental perturbations as thermal discharges and gas supersaturation (Tester and Siniff 1976, 1977). A multi-channel ultrasonic biotelemetry system capable of detecting an animal's location, swimming direction and speed, depth, temperature and light conditions was described by Ferrel et al. (1974). For several years terrestrial ecologists have used radio telemetry to monitor animal activity patterns (Sunquist 1974). While there is no such comprehensive activity research for fish in the literature, certainly the technology is available for such investigations. Clearly underwater biotelemetry is rapidly advancing fields of great value to aquatic researchers.

To determine the effect of thermal discharges on yellow perch, I selected biotelemetry methods and equipment developed by the University of Minnesota. These methods have proven successful in tracking several free-ranging species of fish including largemouth bass, Micropterus salmoides, and rainbow trout, Salmo gairdneri, (Winter 1976). Also, Clugston (1973) and Warden and Lorio (1975) have used biotelemetry methods to observe the behavior of largemouth bass relative to environmental alterations.

The major objectives of our research were:

1. Determine the distribution of yellow perch, northern pike, walleye and largemouth bass relative to a thermal discharge.
2. Construct a temperature-sensitive radio frequency tag for small fish and an automatic system to receive and record temperature data.
3. Determine the winter temperature preference of adult yellow perch in the vicinity of a thermal effluent.

This study was accomplished with three subprojects. First, yellow perch were equipped with radio transmitters and tracked in the thermal discharge area to determine winter distribution and temperature preference. During this phase of the study, temperature-sensitive transmitters and an automatic recording system were developed and put into operation. Second, fish from outside the discharge area were equipped with radio transmitters and tracked in an attempt to more fully explain distribution and observe attraction (if any) to the discharge area. The third subproject was a series of associated observations made in conjunction with the above radio tracking studies, in order to substantiate our telemetry inferences. These include mark-recapture operations, comparative survey information, catch per unit effort, sex ratio, spawning condition, and gonado-somatic indices of yellow perch within and outside the thermal discharge area. Also, several northern pike, walleye and largemouth bass were equipped with transmitters and tracked for comparative behavior information relative to yellow perch.

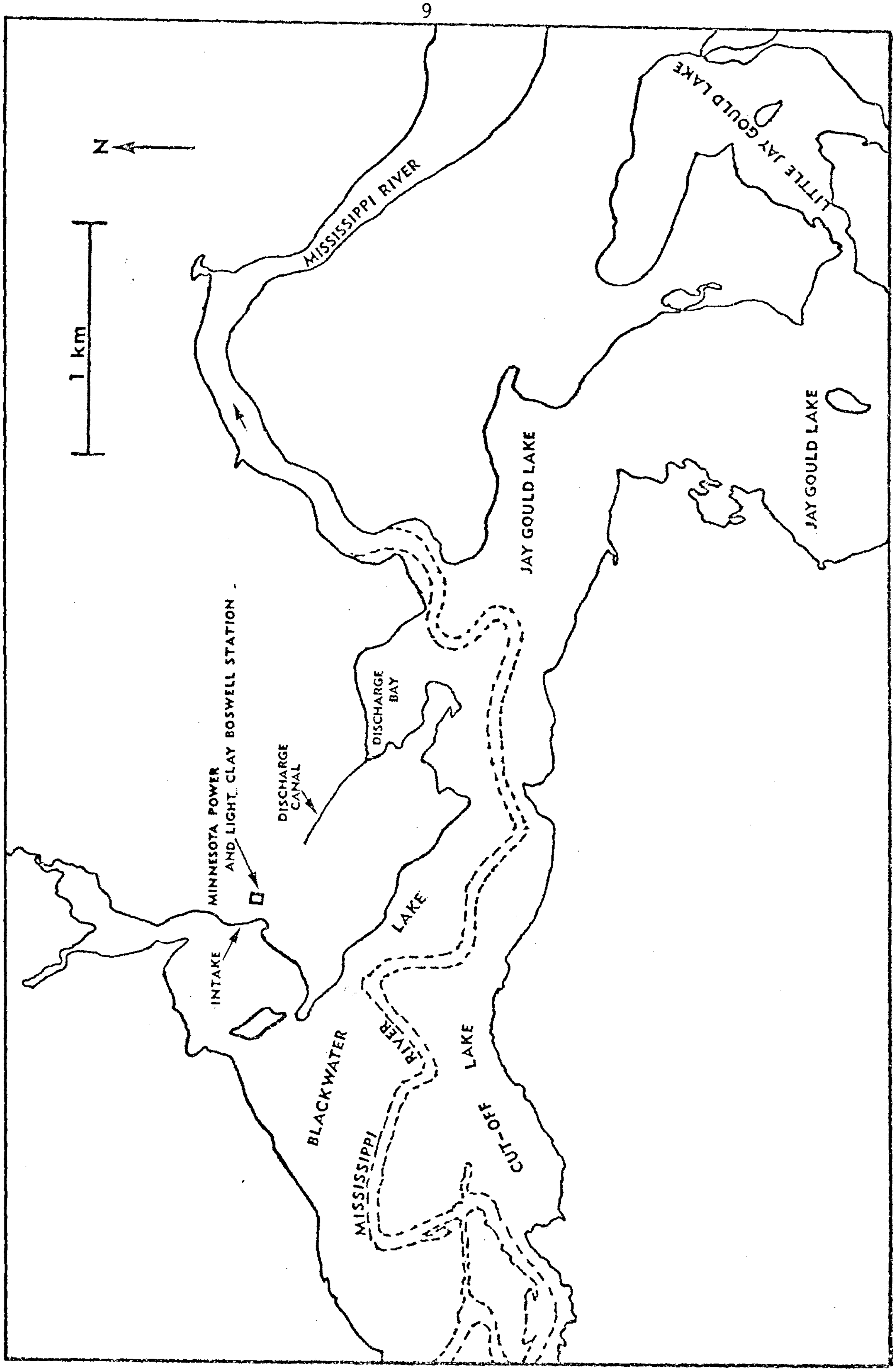
STUDY AREA

This investigation was conducted during the fall, winter, and spring months of 1975 and 1976 in the Pokegama reservoir area of the Mississippi River in Itasca County near Cohasset, Minnesota (Fig. 1). At this location, Minnesota Power and Light Company's Clay Boswell Steam Electric Station uses river water for once-through condenser cooling of two 75 megawatt generating units.

The Pokegama reservoir was created by the construction of a dam 4.8 km west of Grand Rapids, Minnesota. It covers 3240 surface-area hectares consisting of a diverse mixture of lake and river habitats. The area was described by U.S. Department of Interior (1957) and Peterson (1962). In summary, the reservoir is located in a region of ground moraines developed in recent glacial times. The terrain is level to moderately hilly consisting of well-drained uplands pocketed with lakes, bogs, and swamps. The bulk of the glacial drift is composed of blue till, sand, clay, gravel, and boulder. Most of this region originally supported stands of conifers, especially white pines and red pines, and hardwoods; however, logging and forest fires have changed the vegetation to a predominantly second-growth hardwood forest. Bogs and swamps support spruce, tamarack, willow, alder, and dogwood. Agricultural land has been maintained in the forest openings and clearings where hay and small grains are raised.

Immediately upstream from the Clay Boswell Station, the Mississippi River meanders in a 2.5 m deep channel between Cutoff and

Figure 1. Mississippi River and adjoining lakes in the vincinity of Minnesota Power and Light Company's Clay Boswell steam electric station.


N
1 km
MISSISSIPPI RIVER
LITTLE JAY GOULD LAKE
JAY GOULD LAKE
JAY GOULD LAKE
MINNESOTA POWER
AND LIGHT, CLAY BOSWELL STATION
DISCHARGE BAY
DISCHARGE CANAL
INTAKE
BLACKWATER
LAKE
MISSISSIPPI
RIVER
CUT-OFF
LAKE

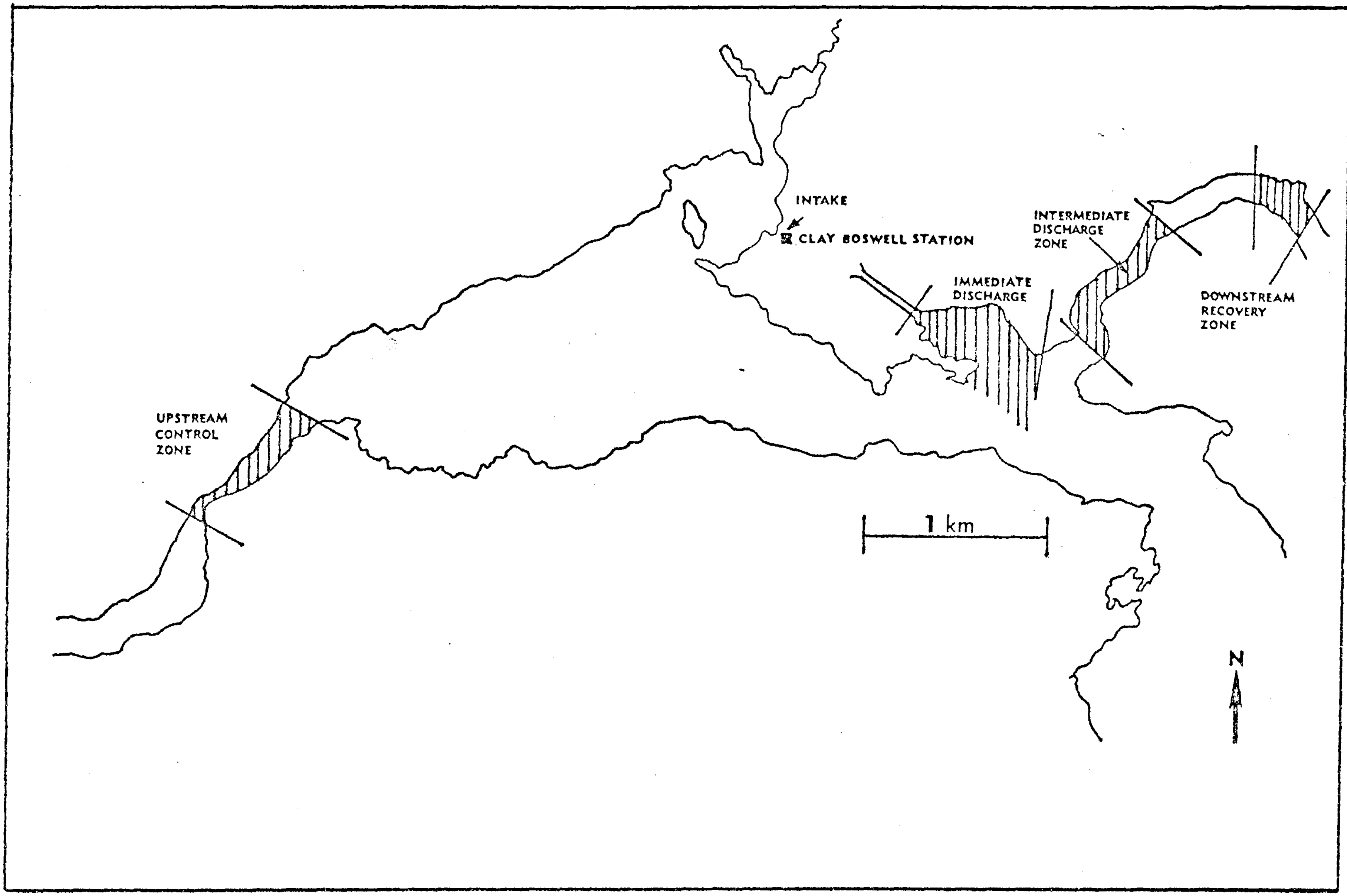
Blackwater Lakes (Fig. 1). Except for the northwest bay of Blackwater Lake which reaches a depth of 21 m, both of these lakes are shallow (approximately 1 m deep) and support a large crop of wild rice. The plant intake is located on the northwest bay of Blackwater Lake. At the downstream end of Blackwater Lake the river bends abruptly north, isolating the 12.9 ha northeast bay of Jay Gould Lake. This bay receives the thermal discharge from the Clay Boswell Station. Downstream from the confluence of the discharge bay the river flows for 5.6 km in a nearly trapezoidal channel approximately 2.5 m deep with gradually sloping banks and scattered shoal areas to the termination of the reservoir at the Pokegama dam. The average monthly discharge rates for the past 25 years range from 920 to 105096 liters per second (l/s).

The normal seasonal river temperatures vary from $0^{o}C$ to $27^{o}C$. Deeper lakes in the area are typical dimictic lakes. Jay Gould Lake and Little Jay Gould Lake have very low concentrations of dissolved oxygen in the hypolimnion. Pokegama Lake has sufficient oxygen below the thermocline for fish life (Peterson 1962).

Concurrent with our study, Minnesota Power and Light Company (MP&L) prepared an environmental impact statement relative to present and proposed future plant operations. The following information was taken largely from MP&L (1977) data. The area near the Clay Boswell S.E.S. was divided into the four zones depicted in Figure 2.

The upper Mississippi in the vicinity of the Clay Boswell S.E.S. is characteristically a slightly alkaline hardwater system. The water has a brown stain, turbidity units expressed in Jackson Turbidity

Figure 2. Minnesota Power and Light Company's environmental impact statement study zones. (Modified from MP & L (1977) by permission).


INTAKE
CLAY BOSWELL STATION
INTERMEDIATE
DISCHARGE
ZONE
IMMEDIATE
DISCHARGE
DOWNSTREAM
RECOVERY
ZONE
UPSTREAM
CONTROL
ZONE
1 km
N

Units ranged from 0.8 to 5.6. Nutrient levels are relatively low. Table 1 summarizes the water chemistry observations from MP&L (1977) for the area near the Clay Boswell Station. The water chemistry parameters substantially altered by plant operations appear to be sulfate, copper, total suspended solids, total dissolved solids and hardness. Total residual chlorine (TRC) concentrations were below 0.4 mg/l at the seal well. Further, a maximum of 0.1 mg/L TRC was detected in the discharge canal.

Fourteen species of aquatic macrophytes were found in the area near the Clay Boswell Station. Tables 2 and 3 summarize the species found by location and standing stock. Arrowhead, coon tail, and white water lily appear to be the dominant macrophytes in the discharge area. Wild rice and arrowhead appear to dominate in other areas. A greater number of species and higher standing stock, were observed near the thermal discharge.

In the vicinity of the power plant,107 taxa of macroinvertebrates were found including 68 taxa in the discharge area. Only the upstream control had a greater number, 74. Caddisflies were the most abundant organism collected. Amphipods, turbellarians, and chironomid larvae were also relatively abundant organisms. Only the amphipod, *Hylella azteca*, showed a decrease in the immediate discharge zone. Of the lesser abundant organisms,may flies, beetles, damselflies, and anelid worms decreased in the discharge zone.

The fish community is a northern cool water to warm water transition assemblage. Thirty seven species have been collected representing several trophic levels. Muskellunge (*Esox masquinongy*), walleye, northern pike, largemouth bass, yellow perch, sunfish (*Lepomis sp.*),

Table 1. Average concentrations at each zone of the major chemical and water quality parameters at the Clay Boswell S.E.S. from September 17, 1975 to July 8, 1976. (Modified from MP&L (1977) by permission).

Chemical and Water Quality Parameters	Upstream Control	Intake	Immediate Discharge	Intermediate Discharge	Downstream Recovery
Dissolved Oxygen			8.6	9.5	9.4
Total Alkalinity (as $CaCO_3$)	120	130	140.6	138	137
BOD (5)	3.05	3.5	2.5	2.38	2.38
COD	26.5	30.2	29.4	27	33.5
Total Kjeldahl Nitrogen	0.80	0.80	0.75	0.70	0.62
Total Phosphorus	0.035	0.025	0.040	0.033	0.034
Total Suspended Solids	3.0	1.75	4.33	3.0	3.0
Total Dissolved Solids	146	165	226	174.2	167.2
pH (Units)	7.8	8.1	8.05	8.1	8.1
Sulfate	3.0	6.3	39.25	11.7	8.9
Turbidity (JTU)	2.15	1.4	2.58	2.0	2.0
Total Hardness (as $CaCO_3$)	120	135	177	145.6	143
Iron	0.25	0.18	0.26	0.23	0.22
Zinc	0.031	0.036	0.034	0.024	0.038
Total Copper	0.01	0.01	0.02	0.02	0.01

Table 2. Summary of aquatic macrophytes found in each sampling zone at the Clay Boswell S.E.S from August 27, 1975 to August 13, 1976. (From MP & L (1977) by permission.)

Species	Upstr. Contr. Zone	Immed. Dischg. Zone	Intermed. Dischg. Zone	Dwnstr. Recov. Zone
1. American elodea *Elodea canadesis*	X	X	X	
2. Arrowhead *Sagittaria latifolia*	X	X	X	X
3. Bladderwort *Utricularia sp.*	X	X	X	X
4. Buttercup *Ranunculus sp.*			X	
5. Coontail *Ceratophyllum sp.*	X	X	X	X
6. Giant duckweed *Spriodela polyrhiza*	X	X	X	
7. Leafy pondweed *Potamogeton foliosus*		X		
8. Pond lily *Nuphar advena*		X		
9. Pondweed *Potamogeton sp.*		X		
10. Star duckweed *Lemna trisulca*	X	X	X	X
11. Water milfoil *Myriophyllum sp.*	X	X		
12. Water stargrass *Heteranthera dubia*		X	X	
13. White water lily *Nymphaea tuberosa*		X	X	X
14. Wild rice *Zizania aquatica*	X	X	X	X
Total no. species	8	13	10	6

Table 3. Average results of aquatic macrophyte standing crop determination from 9 one meter square plots, 3 each on August 27, 1975, June 2, and August 13, 1976 at the Clay Boswell S.E.S. (Modified from MP & L (1977) by permission.)

LOCATION	SPECIES	WET WT. GMS.	DRY WT. GMS.
Immediate Discharge Zone	Arrowhead	18,434	1,282
	Bladderwort	57	4
	Coontail	3,348	348
	Elodea	241	26
	Giant Duckweed	1	1
	Leafy Pondweed	240	32
	Pond Lily	846	80
	Water Stargrass	13	2
	White Water Lily	4,572	554
	Wild Rice	266	25
	Total (gms)	29,160	2,459
	Average(gms/m^2)	3,240	273
Intermediate Discharge Zone	Arrowhead	9,794	695
	Bladderwort	13	1
	Buttercup	13	1
	Coontail	3,893	259
	Elodea	242	19
	Giant Duckweed	5	1
	Star Duckweed	1,807	178
	Water Stargrass	20	2
	White Water Lily	278	30
	Wild Rice	4,244	463
	Total (gms)	20,309	1,649
	Average(gms/m^2)	2,257	183
Upstream Control Zone	Arrowhead	2,523	193
	Bladderwort	626	30
	Coontail	894	80
	Elodea	20	2
	Giant Duckweed	40	2
	Star Duckweed	206	14
	Water Milfoil	618	44
	Wild Rice	14,182	1,756
	Total (gms)	19,109	2,121
	Average(gms/m^2)	2,123	236
Downstream Recovery Zone	Arrowhead	5,707	378
	Bladderwort	665	74
	Coontail	418	53
	Star Duckweed	1,126	67
	White Water Lily	251	13
	Wild Rice	1,232	102
	Total (gms)	9,399	687
	Averabe(gms/m^2)	1,044	76

rock bass (Ambloplites rupestris), and crappie (Poxomis sp.) are of the most interest to the sports fishing industry. The greatest density and numbers of species were collected in the thermal discharge area. The more themophillic species of centrarchids and ictalurids were especially prevalent in the immediate discharge. Perch, bullheads (Ictaluridae), suckers (Catostomidae), dogfish (Amia calva) and burbot (Lota lota) have been taken commerically by rough-fish removal contract since 1944.

The principal function of the Pokegama reservoir is water level control and storage in the upper Mississippi. Recreational activities comprise the majority of human utilization of the river and lakes. Sports fishing is a major part of the local economy and small pleasure craft make up the bulk of river traffic. Waterfowl hunting attracts large numbers during the fall months. Commerical resources are principally the wild rice harvest and rough-fish removal.

Clay Boswell Station Units One and Two were put on-line in 1958 and 1960, respectively. Each has a net generating capacity of 69 megawatts. Together the units use Mississippi River water at the rate of approximately 409000 liters per minute (6800 l/s) for condensor cooling during the spring, summer, and fall months. This results in water temperatures increasing an average of 7.2^{o}C above ambient. During winter months, a 204000 liters per minute (3400 l/s) rate is maintained for cooling resulting in an average design temperature increase of 15^{o}C. Heated water is discharged into the receiving bay via a 442 m x 15 m canal at a flow rate of 1.1 meters per second (m/s) spring, summer, and fall and 0.5 m/s rate during winter months. When both units are operating at 100% capacity the maximum heat rejection rate is 8.5×10^7 k cal/hr.

Ecological changes due to the thermal effluent alone are difficult to determine. The receiving bay is a relatively shallow lentic environment. Contrasting this area to more riverine environments does not allow for direct comparisions. However, the most notable changes associated with the increased temperature are an increase in copper and sulfate concentrations, and the introduction of a .003 to .05 m/s velocity current to the receiving bay. Other changes that appear to be caused at least in part by the thermal discharge are an increased macrophyte standing stock, a decrease in abundance of the amphipod, Hyllela azeteca, and a concentration of fishes, especially the thermophillic ictalurids and centrarchids.

The Cohasset area of the Mississippi River near MP&L's Clay Boswell Station was selected for several reasons, both biological and logistic. Minnesota Department of Natural Resources assessment netting records indicated a sizable walleye and perch population in the vicinity. The Clay Boswell Station has two independent once-through cooling units resulting in a combined temperature increase of 15°C. This relatively warm discharge offered the best opportunity to observe temperature related effects. Further, with two cooling units the likelihood of a complete thermal discharge interruption was reduced. Cohasset is conveniently located to both the University of Minnesota and the Duluth Water Quality Laboratory, a consideration necessitated due to the relatively sophisticated equipment utilized combined with adverse weather conditions. An environmental impact analysis prepared concurrently by MP&L produced much needed background and supporting data gathered independently. Finally, sports fishing is popular in the vicinity and cooperation of area residents, resort owners, D.N.R. personnel, and MP&L officials was essential.

METHODS

Collecting and Tagging

Fish for radio tagging were collected principally with five single pot trap nets set between 1 m and 3 m deep. Nets were pulled every morning during trapping periods, weather permitting. All fish were removed and the numbers of each species recorded for survey information. Fish retained for tagging were transported in tubs via boat to a holding tank. Occasionally fish were provided by anglers, commercial fishermen, Wapora Inc. trap nets and Minnesota Power and Light Company's electrofishing operations.

Fish to be tagged were held in a 600 liter stainless steel tank equipped with a heater and aerator. I attempted to maintain temperatures in the holding tank approximately the same as the temperature of the area where fish were collected by utilizing various combinations of insulation, heating, aeration, and freshwater flow from the Mississippi River.

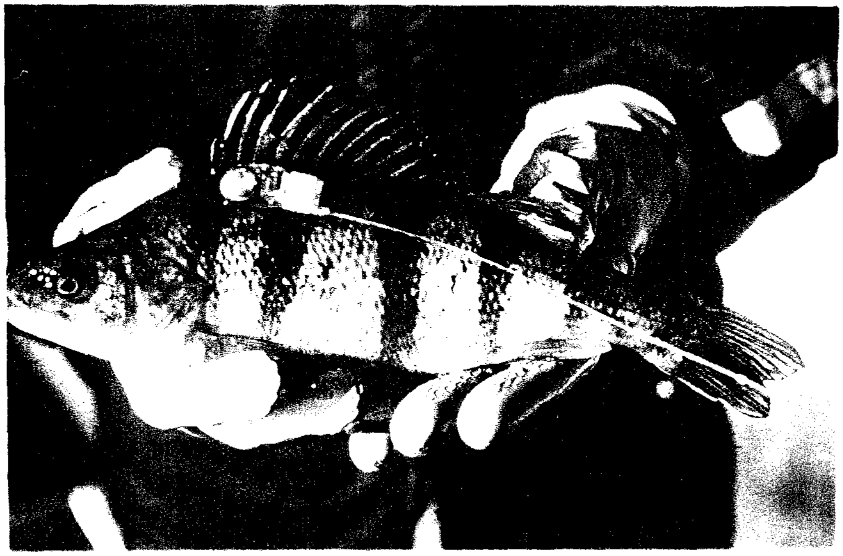
Prior to the tagging operation fish were weighed, measured, sexed, and a scale sample taken. For tagging, fish were placed in a trough and kept moist by dripping water from a wet towel. Radio tags were applied externally by a subdorsal fin mount. (Fig. 3). Using either a hypodermic needle or a surgical needle two teflon-coated wires

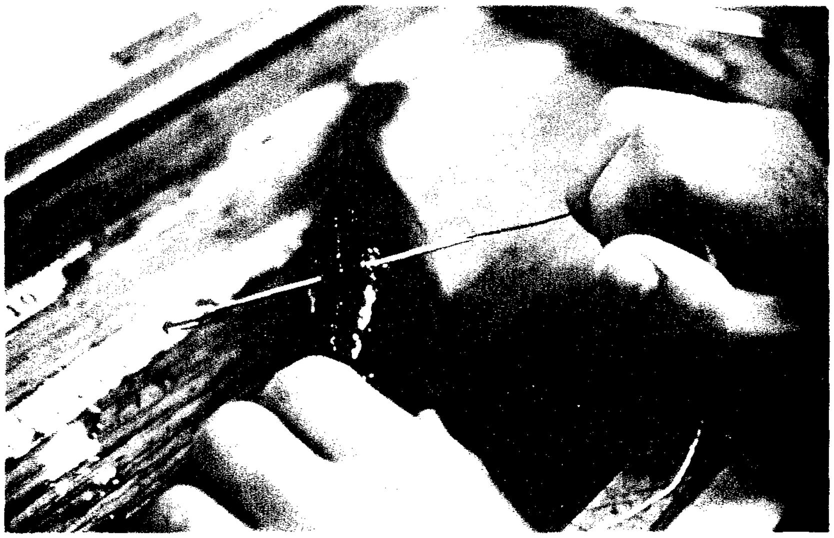
Figure 3. Attaching radio transmitter.

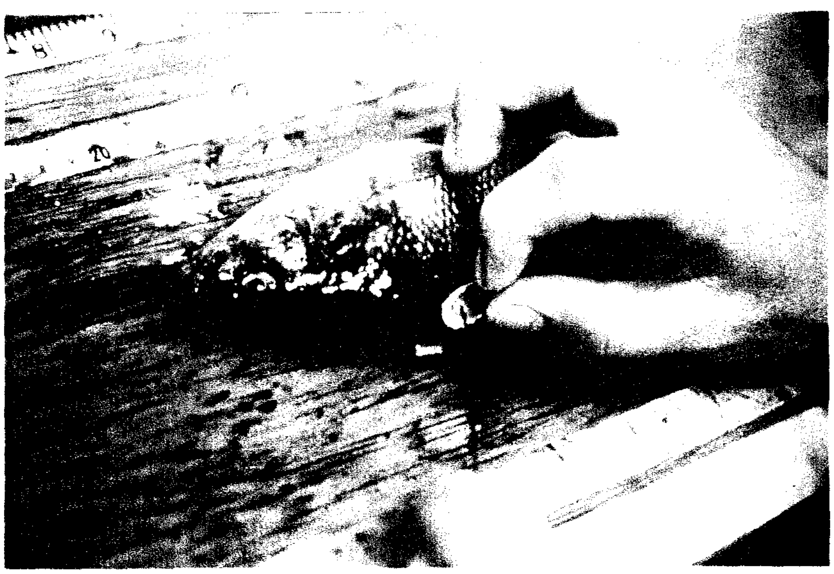
a) Sub dorsal mount

b) Feeding attachment wire through muscle tissue.

c) Attaching plastic backing plate.







protruding from the transmitter were threaded through the supporting tissue between pterygiophores immediately ventral from the dorsal fin (Fig. 3b). A plastic plate was installed on the opposite side of the fish and the attachment wires were tied and the excess clipped off (Fig. 3c). Total time for the tagging operation averaged 3.5 minutes. At no time, however, was a fish held out of water more than 2 minutes before being resubmerged for a time and the operation continued to completion. Fish tagged during the fall and spring months were sedated with Tricaine Methanesulfonate (MS-222) and given a static one hour treatment with Aureomyein (20 ppm). Fish tagged during winter months were not treated chemically.

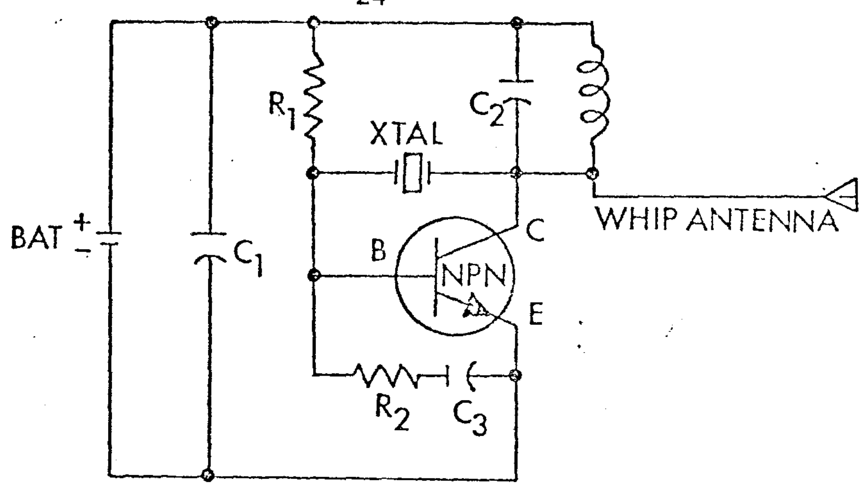
Fish generally acclimated to the tag within 0 to 25 minutes i.e., they regained equilibrium and swam normally in the holding tank. Following an acclimation and observation period of two to four hours, radio tagged fish were released at their respective trapping sites.

Fish Transmitters

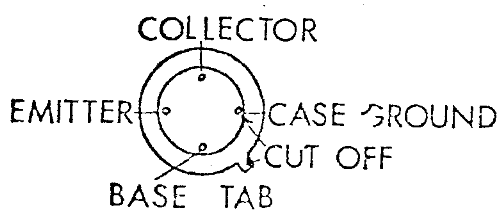
Two types of 53 MHz radio frequency transmitters were used during this study. Initially a transmitter circuit similar to that described by Cochran and Lord (1963) was modified and miniaturized by the University of Minnesota's Cedar Creek Bioelectronics Laboratory. Secondly, a temperature-sensing transmitter was designed, miniaturized, field tested, and drift tested by this Laboratory.

The location transmitter circuit and component arrangement are shown in Figure 4. The original design was for a continuous wave ("whistling") signal. Capacitor C_3 and resistor R_2 were added to cause the transmitter to emit a pulsed signal. Pulsing signals reduced

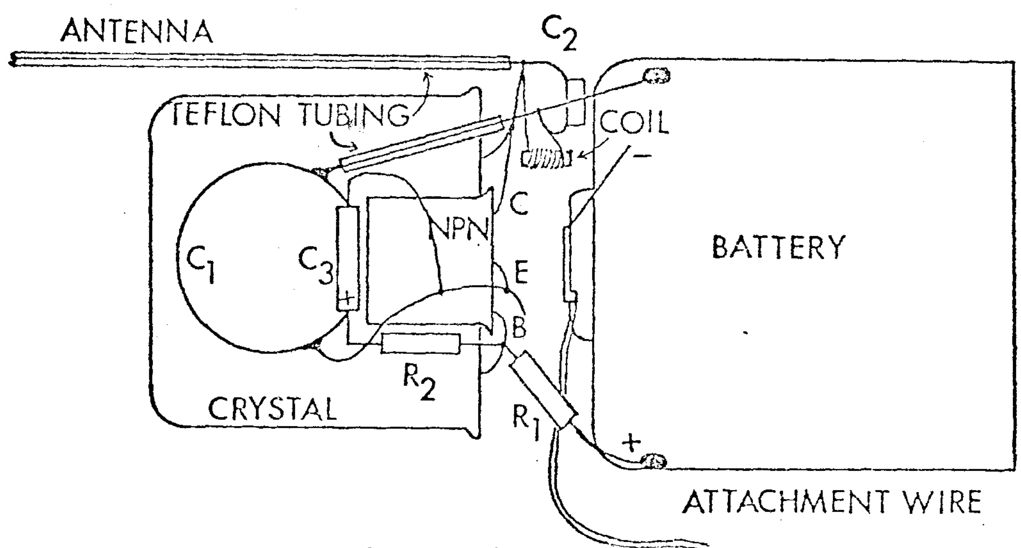
Figure 4. Transmitter circut diagram and component arrangement.



CIRCUIT DIAGRAM



TRANSISTOR LEAD CONFIGURATION
AMPEREX A415



COMPONENT ARRANGEMENT

power consumption and therefore increased transmitter life. The pulse width (on time) of our transmitters was 0.02-0.025 seconds and the pulse rate was between 60 and 120 pulses per minute. The duty cycle or ratio of on time to total time was 3% $\pm$ 1%.

Technical specifications for the location transmitter are summarized in Table 4. Transmitter life, size and range are parameters of most concern to biologists. The theoretical life based on a transmitter current drain of 0.3 - 0.4 m.a. with a Mallory 675 battery was approximately 30 days. Actual life averaged 33 days. It should be noted, however, that the average actual life was biased to the low range as during certain tracking periods I could not always determine if the transmitter had stopped because the battery expired or if the fish had simply moved out of range or was captured and the tag not returned. Size of perch location transmitters averaged 3.3 cm long, 1.3 cm wide, and 0.6 cm deep. The final weight of the transmitter on the fish, i.e., components plus encapsulating material minus excess attachment wires minus water volume displaced, averaged 3.5 g. Maximum range was also difficult to determine exactly as range varied with depth of the fish, meteorological conditions, water conductivity, and radio frequency interference. Winter et al. (1978) discussed attenuation of radio frequency signals in water. They found that in Lake Bemidji (water conductivity 30.0 mmho/m), an area similar to the Mississippi River at Cohasset (water conductivity 32.0 mmho/m), 50% of the transmitter's surface range was lost at 4 meters (Figure 5). Also, Tester and Siniff (1977) measured the increased attenuation of higher radio frequency range transmitters (Figure 6). My approximate working range was 0.7 km. Under ideal conditions signals were audible

Table 4. Fish radio tag specifications.

Frequency:	53 to 54 mhz.
Battery:	Mallory 625, 675, RM-1 (Experimentally, lithium cells)
Dimensions, Location Transmitter:	(using 675 battery) 3.3 cm X 1.1 cm X 0.9 cm dry weight 6.0 g to 6.5 g weight in water 3.5 g
Dimensions, Temperature Transmitter:	4.6 cm X 1.2 cm X 0.9 cm dry weight 9.5 g - 11.0 g. weight in water 4.9 g.
	size and weight include transmitter potted and sealed and backing washer.
Potting Compound:	Scotch Cast epoxy sealed with a final coat of clear fingernail polish.
Backing washer:	1.6 mm low density polyethylene cut and ground to proper size and shape.
Attachment wires:	24 ga. silver-copper conductor wire covered with extruded teflon.
Antenna:	Teflon covered twist-o-flex dental type stainless steel.
Approx. life and range:	(675 battery) - 0.7 km. 30 to 40 days

Figure 5. Attenuation of radio signals with increasing depth in lakes with different conductivities. Curves marked with dots and squares are from Lake Superior (8.0 mmho/m) and triangles are from Lake Benidji (30.0 mmho/m). (Winter et al. 1978).

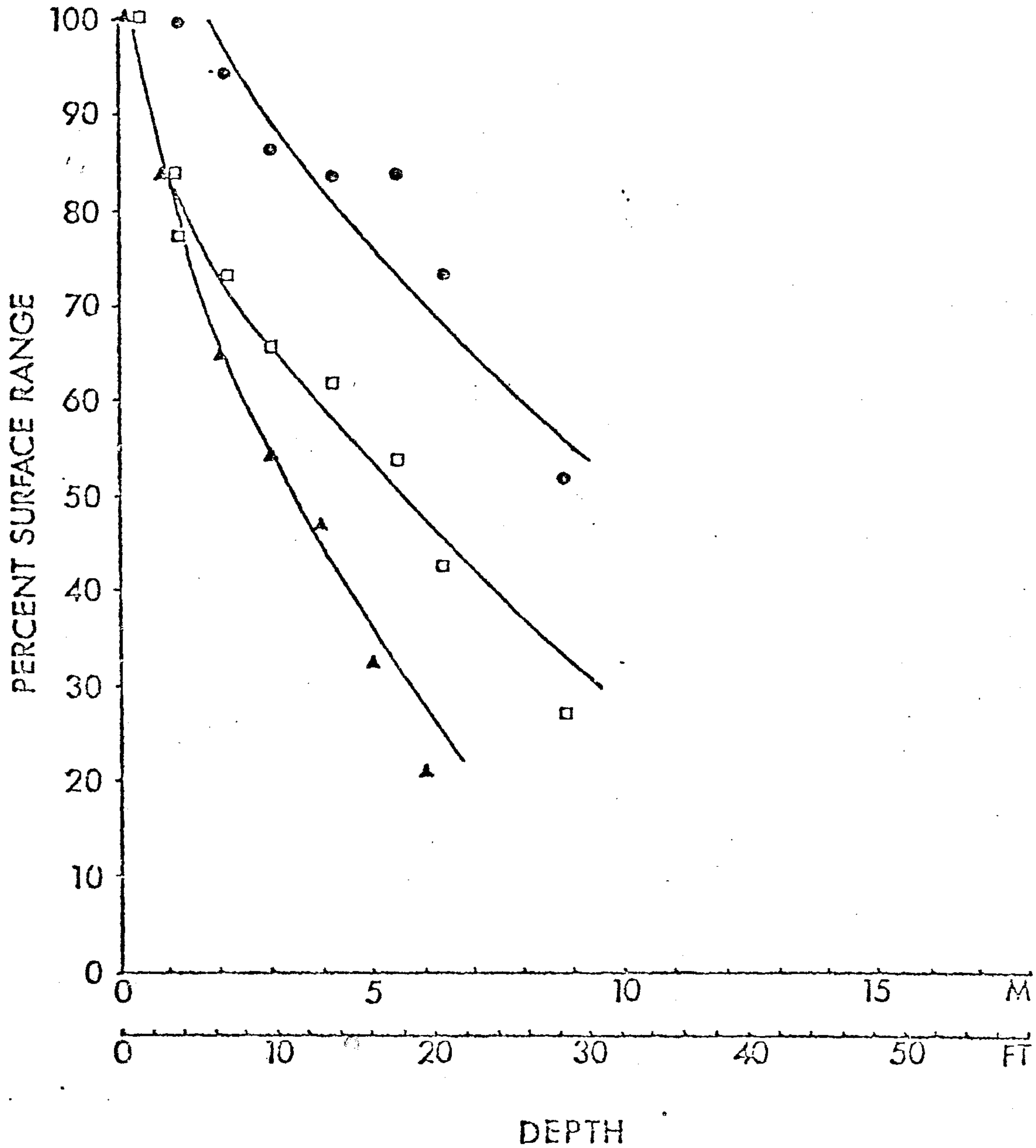
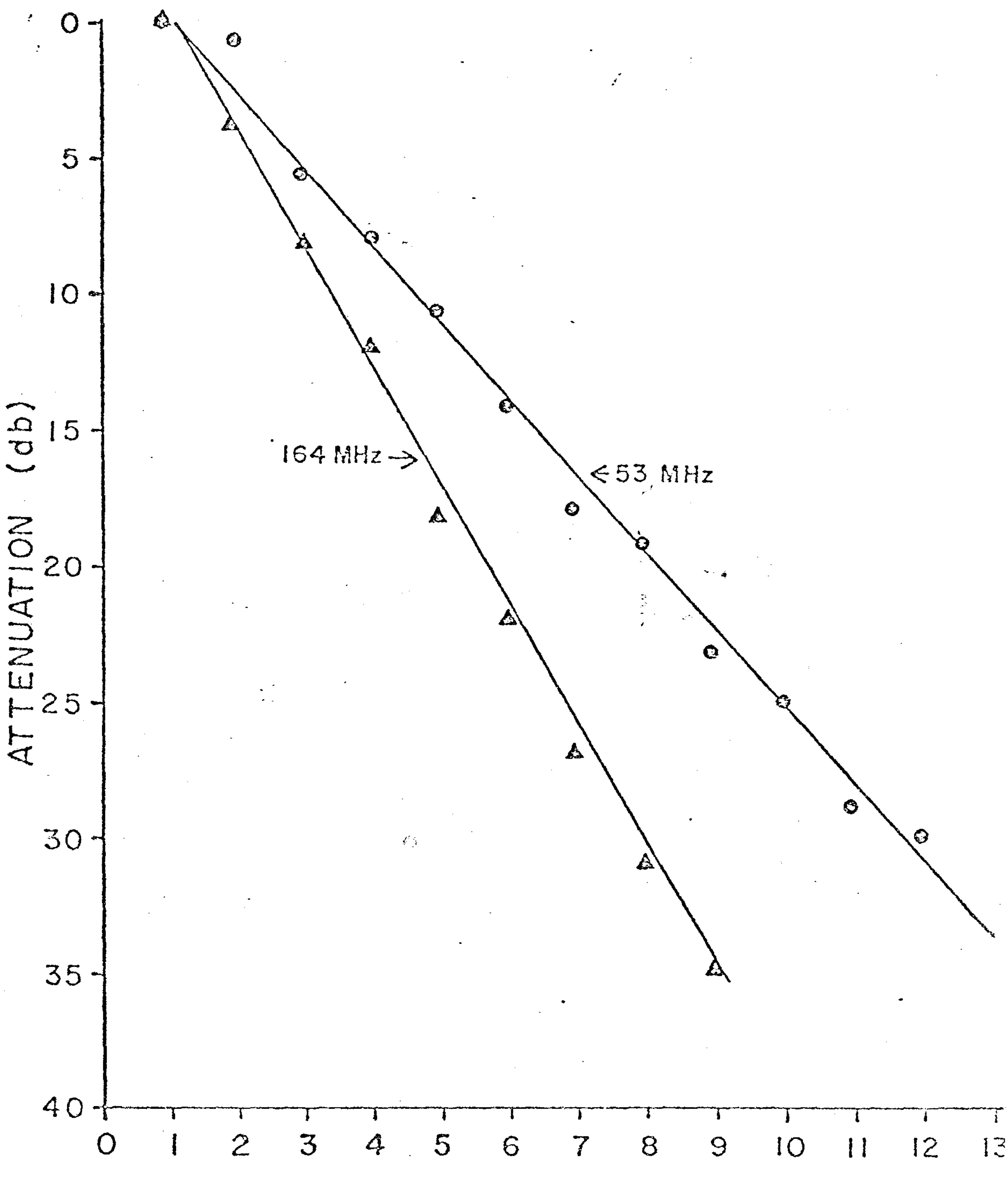

PERCENT SURFACE RANGE
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
M
0
10
20
30
40
50
FT
DEPTH

Figure 6. Radio frequency attenuation vs. depth. Water conductivity 7.0 mmho/m. (Tester and Siniff, 1977).



164 MHz
53 MHz
ATTENUATION (db)
DEPTH (METERS)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13

for greater than 1.6 km.

For the temperature transmitter a thermistor and control circuitry were added to a location transmitter, the result being a pulse rate that is temperature-dependent. Pulse width remains constant but the spacing between pulses varies with temperature.

Three areas were critical in the development of the temperature transmitter circuit (Figure 7). First, the pulse rate had to remain constant with changes in power supply voltage. This was especially critical when working with lithium 2.8 v batteries. By inserting Rs_1 and Rs_2 (Figure 7), pulse rates were stabilized for changes in power supply voltage. Lithium batteries were not used in this study; however, weight and life considerations make lithium cells preferable for many aquatic applications and will be utilized extensively when smaller sizes become available. A single 1.4 v. mercury cell (RM675) was used to power temperature transmitters. Pulse rate voltage stability of the temperature-sensing circuitry was found to be greater at this voltage eliminating the need for Rs_1 and Rs_2. Table 5 summarizes pulse interval variation versus changes in supply voltage.

Second, long-term drift had to be minimal so that temperature transmitters retained their original calibration over the expected life of the unit. Figure 8 summarizes drift testing data. Worst case drift was found to be $1^{o}C$ at $0^{o}C$ and $0^{o}C$ to $15^{o}C$ and generally much less. These tests were made over a ten-week period, but shorter term observations were expected to measure temperature more accurately. Since the bulk of the drift occurred during the first two weeks of testing, long-term drift could probably be reduced by pre-aging tags

Figure 7 . Temperature transmitter circut.

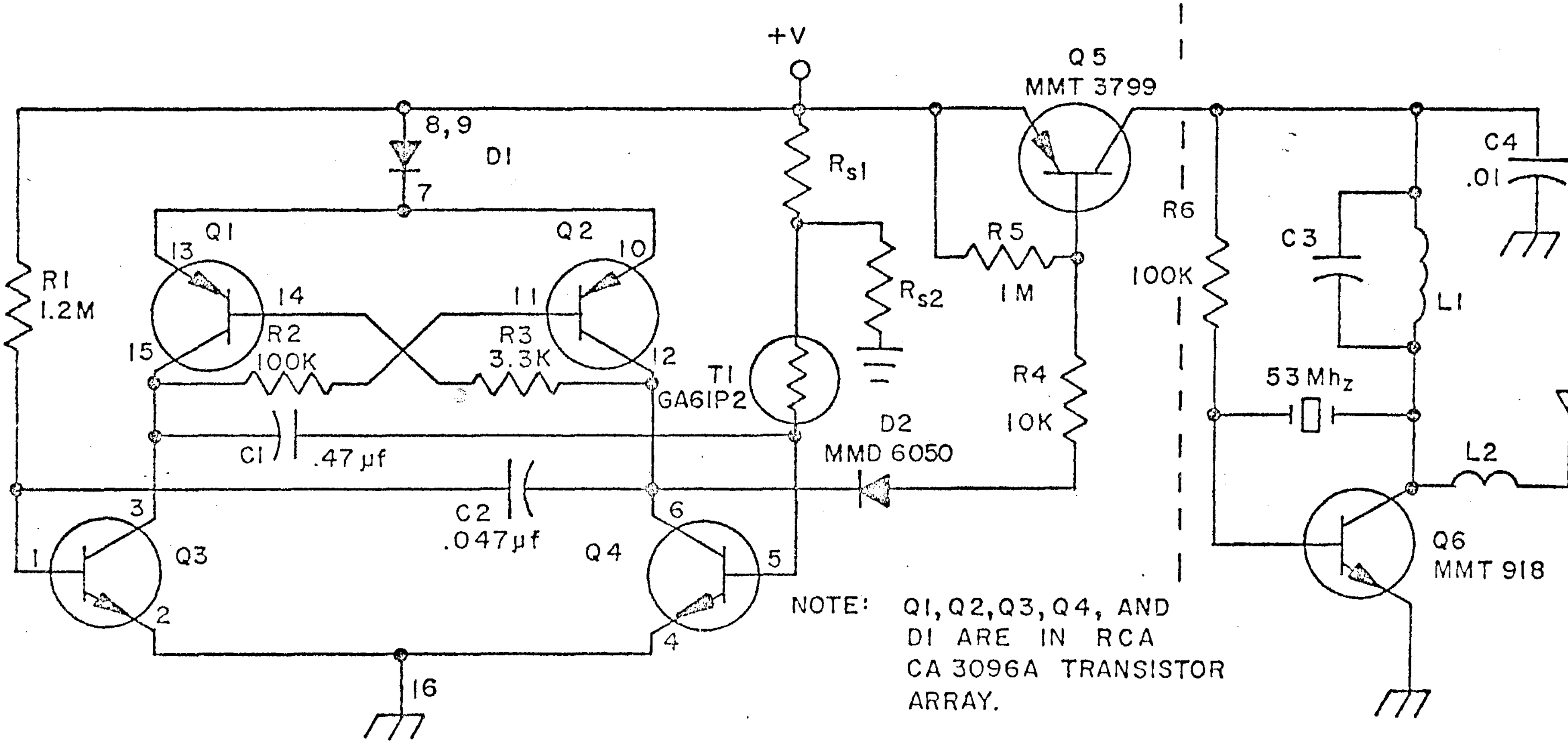

+V
Q5
MMT 3799
8,9
D1
7
R_{s1}
C4
.01
R6
Q1
Q2
13
10
R5
C3
1M
R_{s2}
100K
14
11
L1
R1
1.2M
R2
R3
15
100K
3.3K
12
T1
GA61P2
R4
53 Mhz
D2
10K
C1
.47 µf
MMD 6050
L2
3
C2
6
.047µf
1
Q3
Q4
5
Q6
MMT 918
2
4
16
NOTE: Q1, Q2, Q3, Q4, AND D1 ARE IN RCA CA 3096A TRANSISTOR ARRAY.

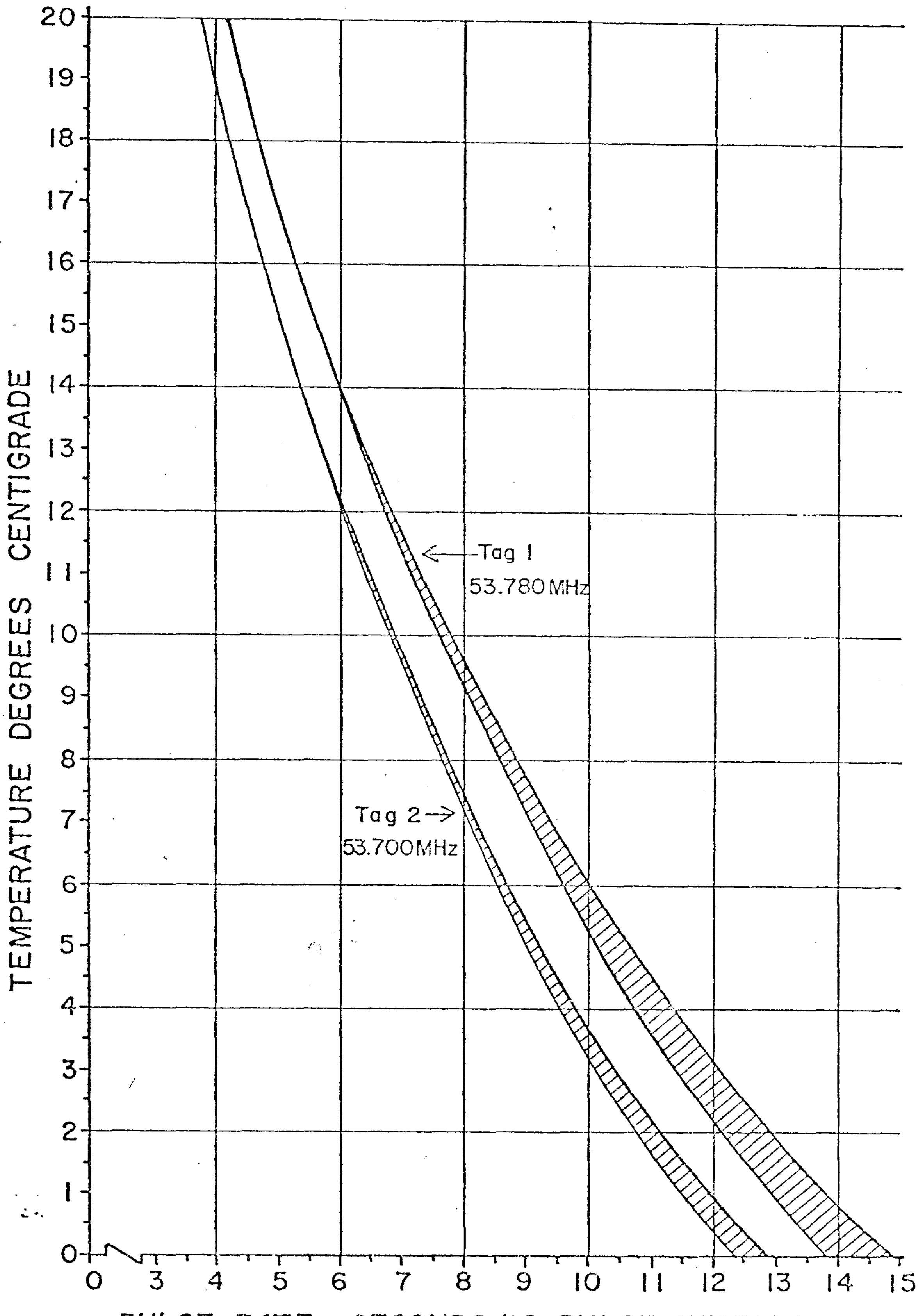
Table 5. Pulse interval variation versus supply voltage (2.8 volt nominal lithium cell).

Thermistor Resistance	Cap. vs	Battery Voltage 2.6	2.8	3.0
		Pulse Interval (Milliseconds)		
488 k	.47 uf	656	656	656
1.0 M	.47 uf	1110	1109	1109
1.5 M	.47 uf	1552	1548	1548
2.04 M	.47 uf	2073	2067	2063
2.5 M	.47 uf	2518	2510	2507

Pulse interval variation versus supply voltage (1.35 volt nominal mercury cell).

Thermistor Resistance	Cap. vs	Battery Voltage 1.2	1.3	1.4	1.5
		Pulse Interval (milliseconds)			
470 K	.47 uf	158	160	162	165
680 K	.47 uf	210	211	212	214
1.0 M	.47 uf	341	342	343	346
1.5 M	.47 uf	472	472	472	474
2.2 M	.47 uf	700	700	700	700
3.3 M	.47 uf	983	983	983	983

Figure 8. Envelope of long term temperature transmitter calibration drift. Calibration checked: 10/5/76, 10/19/76, 11/2/76, 11/17/76, 12/21/76.


20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
TEMPERATURE DEGREES CENTIGRADE
Tag 1
53.780 MHz
Tag 2
53.700 MHz
0
3
4
5
6
7
8
9
10
11
12
13
14
15
PULSE RATE: SECONDS/10 PULSE INTERVALS

before calibration.

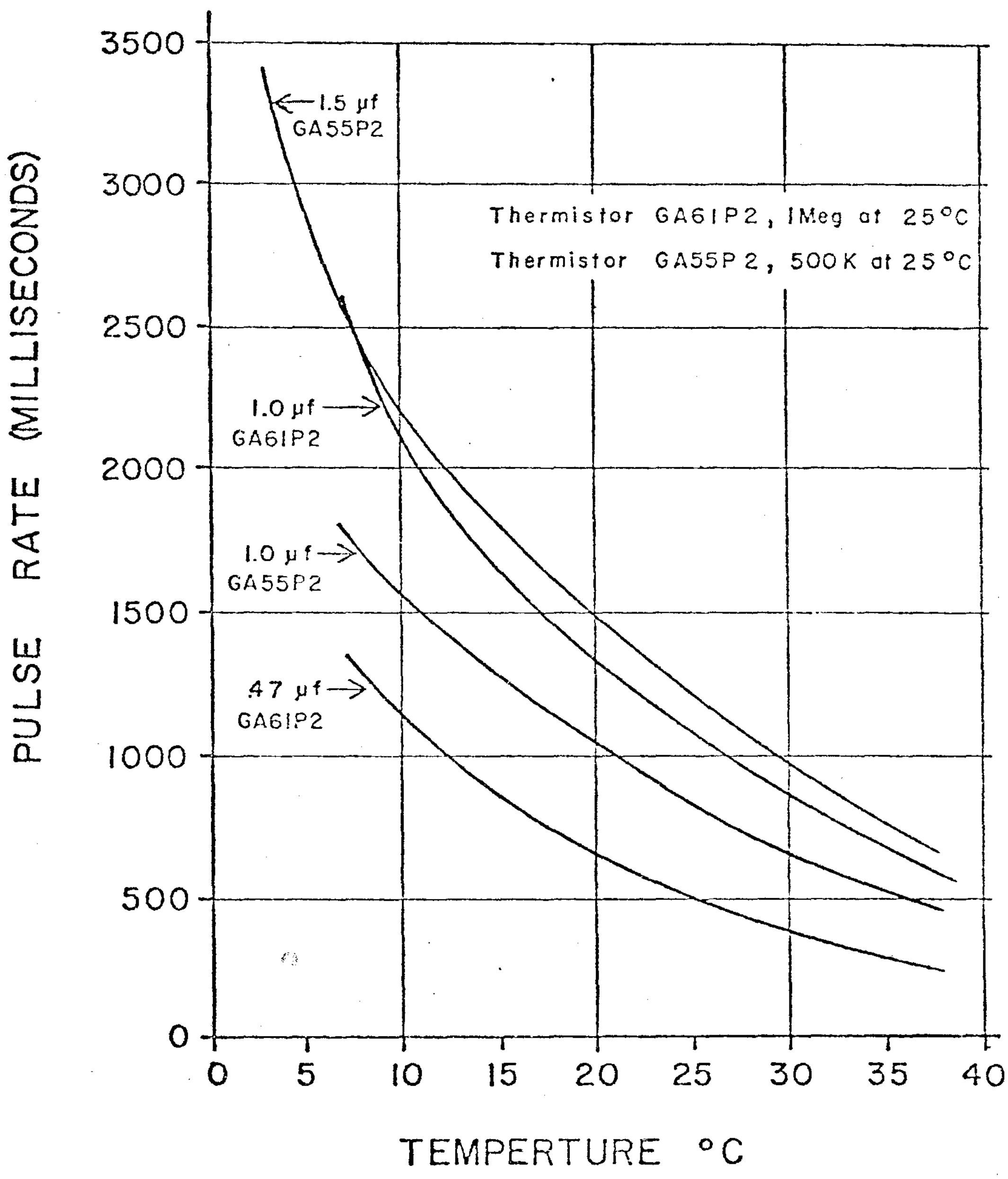
The third design goal was to obtain a range of optimum sensitivities from 0-25°C. The actual pulse rate for a given temperature or range of greatest sensitivity was determined by the thermistor-timing capacitor combination. By varying this combination, the range of maximum sensitivity was optimized (Figure 9).

Table 4 summarizes technical specifications of the temperature transmitter. Theoretically, life and range parameters should have been similar to those of the location transmitter as the temperature-sensing circuitry only consumed 0.005 to 0.01 ma. The current drain of the entire unit varied with temperature; i.e., as temperature increased, pulse rate increased which increased the current drain. Current drains of 0.3 to 0.7 ma were typical. However, increased loading of the transmitter antenna in water caused a reduction in power output. Base resistor R_6 was lowered from 100 k ohms to 47 k ohms to increase power output. Early models with the 100 k ohm R_6 had greatly extended life of 100 - 120 days, but a range of only approximately 150 meters. Later model transmitters had life and range parameters similar to location transmitters. With the added circuitry, perch temperature transmitters were slightly larger than location transmitters. Size of perch temperature transmitters averaged 4.6 cm long, 1.2 cm wide and 0.9 cm deep. The final weight in water of the temperature transmitter averaged 4.9 g.

After construction a numbered identifier label with tag return information was taped to the crystal. Transmitters were then encapsulated in Scotch cast #5 electrical resin (3M Company). This

Figure 9 . Temperature transmitter pulse rate vs. Temperature, Thermistor-Capacitor combinations.

PULSE RATE VS TEMPERATURE



compound made the units water-tight and supported all components. After the resin hardened,the excess was ground off and the transmitter package streamlined with a electric grinder. After allowing the tags to stabilize 24 hours, temperature transmitters were calibrated in agitated water from 0 - 20°C. Immediately prior to fish tagging, the final battery connection was completed and a coat of quick-drying final sealant was painted on the entire transmitter. Marine epoxy was used initially as a final sealant; however, it tended to become cloudy with age. Clear fingernail polish was found to dry faster and remain transparent, thus, tags could be more easily identified.

Tracking and Recording

Fish location and temperature information was collected using 53 MHz radio frequency receivers in conjunction with yagi and loop antennas. An important feature of radio frequency telemetry is the flexibility available for data collection. Locations were obtained by triangulation from shore towers and mobile tracking equipment. Temperature information was collected at a remote recording station and manually with a stop watch.

Fifty three MHz receivers used for location and manual temperature information were constructed by the Cedar Creek Bioelectronic Laboratory. These receivers were capable of distinguishing 100 different transmitters (fish) spaced 10 KHz apart. Animals were located by triangulating from three, 4 element yagi antennas mounted on 7 m semi-permanent shore towers around the discharge bay as described by Winter et al. (1978). Shore towers were calibrated by placing transmitters at known locations and taking bearings to these locations.

Correction factors were then added or subtracted to fish bearings. When fish left the immediate discharge area, they were located with respect to land marks by hand-held and airplane mounted loop antennas and truck and boat mounted yagi antennas.

Accuracy and precision of animal tracking depend upon three major factors as discussed by Heezen and Tester (1967) and Slade et al. (1965). System errors or the difference between tower-determined bearing and the true bearing to the animal can be caused by wind twisting the antennas, inaccurate calibration, radio frequency interference, etc. Reading errors depend upon the ability of a person to detect signal nulls, resolution of compass cards under differing light conditions, fatigue, etc. Signal nulls are the point at which a transmitter is no longer audible when rotating a directional antenna past a fish. In general two nulls are located symmetrically on either side of the peak signal. Nulls can be discriminated with more precision than maximum signal strength. Thus, determining maximum signal (the bearing to an animal) from two symetric nulls is more reliable than attempting to discriminate actual signal peaks. Finally, accuracy depends upon the animal's location and movement with respect to the receiving antenna. Triangulation errors increase in any direction from the 90^{o} intersection of bearings at the perpendicular bisector of the base line (an imaginary line connecting the antennas). Also, readings to more distant animals inherently have a greater error, as bearing errors have greater significance as distance increases.

Tests conducted on our shore tower array indicated bearing errors caused less than 5 m location errors at 100 m and 43 m at 800 m

(Winter et al. 1978). These results compare closely with Yagi accuracy tests conducted by Marshall (1962, 1963), and Slade, et al. (1965). To determine precision of the system over time I routinely took location bearings to a stationary reference transmitter in the discharge bay from all three towers while tracking fish. When taking bearings from three locations to a point, an error triangle was generated unless all three bearings coincided at exactly the same point. The average size of the triangle over time should have resulted in an area that came close to estimating the precision of the system. I found this area to be 232.4 m^2 or approximately comparable to a circle with a 8.6 m radius. Actual reference transmitter locations were plotted on an X, Y coordinate system as the center of the error triangle. By summing the X and Y locations of a stationary transmitter a standard error of the mean was found to be 6.9 m. on the Y axis and 2.8 m. on the X axis. The center of this reference area was an average of 307 m from the three towers.

Mobile tracking techniques offered the advantage of approaching an animal closely and positioning bearings to cross closer to the optimum 90° intersection. However, reference positions of the antennas were usually somewhat more difficult to determine especially under adverse light and weather conditions. Winter et al. (1978) determined a 14 m bearing error from a distance of 200 m with a truck-mounted Yagi. Loop antennas can be very accurate, especially at close ranges. Verts (1963) reported that triangulations from his truck-mounted loop antenna were $\pm$ 7.6 m at 400 m and $\pm$ 23 m from 800 m. Winter et al. (1978) reported on two tests conducted with loop antennas. The results indicated a calculated mean location error ranging from 0.79 m (5 - 15 m distance class) to 6.49 m (76 - 92 m. class). Our tests with mobile tracking equipment to a transmitter at a fixed location indicated a standard error of the mean to be 5.2 m on the X axis and 8.0 m on the Y axis. In summary, our tests and those in the literature indicate that in general, location errors are less than 10% of the distance from the receiving antenna to the transmitter.

Accuracy and precision tests were not conducted on airplane tracking as locations obtained with this method were only approximate and later pinpointed with other mobile tracking techniques.

I usually attempted to locate all fish at least once a day. Priority was given to those individuals in the immediate discharge area; often these fish were located three to four times a day. On several occasions, 'round-the-clock' tracking at 2 to 3 hour intervals was attempted; however, sporadic radio frequency interference limited the success of these attempts. When fish were located their position was noted in reference to gridded maps of the area.

Fish temperature data were collected in two ways. Temperature transmitter pulse rate was monitored manually with a stop-watch when location data was being obtained. However, the principal source of fish temperature information was an automatic monitoring and recording system designed for this project. The system consisted of a 53 MHz channel-scanning receiver coupled to a pulse rate decoder and strip chart recorder. The equipment was housed in a remote recording shack near the shore of the discharge bay. We found that a near-shore location and low 3 m antennas optimized the signal to interference ratio.

The receiver was similar to the model used to monitor fish location. However, several changes and modifications had been made. Major design changes included the use of a memory into which frequencies could be programmed and later recalled by means of a single selector or scanned automatically by an interval timer. This option proved valuable in two applications. First, in tracking from an aircraft where it was necessary to scan for a number of animals in a short period. Individual animals could be tuned rapidly by means of a single switch. Since all channels were locked to a single crystal there was no need to search around a frequency to make sure that a transmitter had not been missed. A second application, and a more important one was in unattended applications where the receiver could scan and record data from the channels that had been programmed into the memory. The scanning rate could be pre-selected so that the receiver looked at one of sixteen channels for periods ranging from 3.7s second to ½ hour.

The receiver had a phase locked loop to detect the signal sent to the decoder. Use of a phase locked loop gave greater noise immunity and made transmitter drift a minor problem because as the loop detected a signal if it was within $\pm$ 2.5 KHz from a set frequency.

Next temperature transmitter signals from the receiver were sent to a pulse rate decoder. The function of this unit was to measure pulse rate and generate a signal to a recording apparatus. Since the pulses from the receiver were not perfectly square, some error resulted depending on where the trigger level was set and how the pulse varied from pulse to pulse. This potential error was reduced by averaging a number of pulses. With this scheme I was dependent only on the triggering time of the start pulse (0th pulse) and of the stop pulse (10th pulse). In addition, the error in these two pulses was divided by a factor of ten. Output of the decoder was available as a digital readout from the front panel, a binary coded decimal signal or from the digital-to-analog (DA) converter. The DA converter was an eight-bit integrated circuit type with its output adjusted to 1 miliampere full scale. The eight-bit converter was capable of dividing the 0 to 1 ma scale in 2^8 or 256 parts.

For my application a Rustrak analog recorder was used. The milliampere current generated by the pulse rate decoder DA converter was sent to the Rustrack where it was recorded on a 3" per hour strip chart.

The entire receiving-recording system was powered by a 12 v automobile battery. Generally I adjusted the receiver scanning rate to monitor each temperature transmitter (fish) for a period of four minutes once every 64 minutes. In conjunction with the scanning system, a second continuous receiving-recording system was installed. This system monitored temperature for a selected individual continuously for 24 hour periods.

<u>Data Analysis: Distribution</u>

Fish located by triangulation were plotted on grid maps of the Cohasset area. Winter and spring telemetry data were analyzed for individual fish with existing University of Minnesota computer programs for home range, distance moved from center of home range, release site and between consecutive sites, distance from discharge point and changes in this last parameter with changing plant operations.

Home range was defined by Hayne (1949) as the area utilized by an animal in the course of normal movements excluding migrations and occasional wanderings. Several methods for determining home range areas have been proposed including home range rectangle, summation of grid squares and minimum area polygon. My analysis was based on an adjusted minimum area polygon method as determined by computer programs described by Siniff and Tester (1965). This procedure was found to be most compatable with non-automatic telemetry operations. To determine home range with the minimum area polygon, all individual fish locations were plotted and the area of the smallest convex polygon enclosing these fixes was computed (Odum and Kuenzler 1955). This minimum area was then adjusted by subtracting any portions that occured on land due to shoreline irregularities. With sufficient location data, adjusted minimum area approached the maximum area utilized by an animal.

Distance analysis for species mobility was accomplished in two manners. First, by defining a fixed point i.e., discharge point, release site etc. and entering this point with all locations for an individual fish on a 'fixed point' problem computer program. Secondly, the distance between consecutive locations was determined by entering all individual fish locations on a 'moving point' computer program. Only those fish with a minimum of two days between fixes while they were in the discharge area were analyzed with this method. The mean distance moved per day was then calculated as the total distance moved between fixes divided the number of days an individual was tracked.

All home range and mobility results were obtained by calculating a mean for each individual under consideration and then averaging these means for an overall species mean. Fish considered in this analysis were those fish maintaining a winter home range at least partially within the discharge area.

Discharge area temperatures were obtained with a yellow springs electrical resistance type thermometer. The discharge point and 3 transects with five equidistant stations per transect were monitored at 0.5 m intervals from surface to bottom on a weekly basis. Winter isotherm maps were constructed from these data for the upper 1.5 m of the discharge bay.

Winter distribution with respect to temperature was analyzed for movement between the discharge bay and thermally unaltered areas by plotting consecutive fish locations on a map of mean winter isotherms. This information was divided into two different types of movement. First, movement between the thermal discharge bay and unaltered areas when individuals were either maintaining a home range at least partially within the thermally affected areas or returned at a later date to the discharge area, were termed 'crossings'. Secondly, movements from the discharge bay to unaltered areas, when the fish did not return to the discharge bay were termed 'dispersals'.

Depth selection was determined by superimposing a transparent bathymetric map of the discharge area on individual fish location coordinates.

Data Analysis: Temperature

Recording tapes were read hourly and winter temperature was analyzed to the nearest $0.1^{o}C$. Temperatures collected manually served to augment and verify those recorded automatically. I also attempted to monitor fish that had moved out of recording range on a daily basis.

Yellow perch winter temperature data were analyzed in several manners with standard (SPSS) statistical programs. First, all winter temperature data were lumped to obtain an overall group mean regardless of fish location. This method ignored the fact that several fish transmitters did not record well due to limited ranges; consequently, these individuals had a limited effect on the mean. Perch such as 1837, 1838 and 1842 that recorded for extended periods contributed proportionately more to the lumped mean. Therefore, a second method was used to determine overall perch winter mean temperature selection. Individual mean temperatures were calculated for fish with more than 20 observations. These means were then averaged so that each individual contributed equally to the overall mean.

To determine mean winter temperature selection when perch were in thermally altered waters, all temperature data greater than $1^{o}C$ were analyzed with the same two methods as presented above.

Diel winter temperature selection was determined by analyzing mean diurnal and nocturnal temperatures for those perch with more than 20 observations in each period. This analysis was performed on both overall data and discharge area data.

Autumn Fish Distribution

Autumn fish distribution was determined by plotting individual fish locations on gridded maps with respect to average fall isotherms.

Associated Studies

Several other studies were carried out in conjunction with our perch telemetry operations. The purpose of these observations was to collect data in order to more fully understand the impact of the thermal discharge on the fish community and correlate it to our perch telemetry observations.

Largemouth bass, northern pike and walleye were also equipped with radio transmitters. Transmitter size and configuration varied. Several models were used including a lithium cell powered unit. Capture, transport, tagging, tracking, recording and data analysis methods for these fish were essentially identical to those used for yellow perch. Yellow perch, largemouth bass, northern pike and walleye not utilized for telemetry purposes were treated in one of two manners. First, length and weight measurements were taken, and then fish were tagged with numbered Atkins tags for mark-recapture information. These fish were handled similarly to telemetry fish; however, tagging time was reduced and because of the larger numbers involved, individuals were anesthetized with MS-222. Finally, samples of yellow perch were preserved for later anatomical observations.

Laboratory studies on preserved specimens involved comparing the gonado-somatic indices of yellow perch collected in the discharge bay with those of perch collected during the same time period from unaltered waters. Gonado-somatic indices were obtained by weighing individual fish then excising and weighing gonads. The index is the ratio of gonad weight to whole body weight expressed as a percent.

Survey information recorded each time nets were pulled included net location and numbers of each species. As spawning season approached, yellow perch sex ratios and spawning condition were also noted.

WINTER DISTRIBUTION RESULTS

During the autumn, winter and early spring of 1975 and 1976, 116 yellow perch, 13 walleyes, 8 northern pike and 2 largemouth bass were equipped with radio frequency transmitters. Winter and early spring fish from the discharge area were monitored for comparative distribution relative to the thermal plume. Included in this group were 24 perch, 2 walleye and 1 northern pike equipped with temperature sensing transmitters. Autumn fish were captured and tagged outside of the discharge area to determine attraction, if any, to the heated area which was closer to the reported temperature preference of yellow perch; at a time when normal seasonal water temperatures were declining. Tables 6 to 10 summarize data concerning numbers of fish, period of observation and quantity of information collected.

Home Range

Analysis of home range data for the four species showed intraspecific distribution differences with respect to biotic and physical factors. By comparing home range size and utilization, and location points with respect to temperature, depth, release site and center of home range, a description of the respective distribution of yellow perch, northern pike, walleye pike and largemouth bass in the area of a thermal discharge was made.

Figures 10 to 17 illustrate examples of consecutive locations and home ranges for yellow perch, northern pike, largemouth bass and

Table 6. Winter and early spring 1975, fish radio tagged and data colleted.

SPECIES	Id. No.	SEX	Wt. Grms.	Date ON (1975)	Date OFF (1975)	Track. Perd. (Days)	No. of loc.	No. of Temperatures
Walleye	100		340	2/5	2/14	10	23	
N. Pike	101		907	2/4	3/18	43	24	
N. Pike	102	F	3969	2/13	5/12	89	104	
N. Pike	103	F	5670	2/16	3/18	31	44	
Lm.Bass	104	M	567	2/16	4/16	60	104	
N. Pike	105	F	3062	2/18	2/19	2	3	
N. Pike	106	F	4309	2/20	3/6	15	28	
Perch	107	F	340	2/25	3/24	28	61	
Perch	108	F	340	2/24	3/28	33	66	
Perch	109	F	340	2/24	4/2	38	57	
Perch	110	F	454	2/26	3/23	26	43	
Perch	111	F	340	2/26	4/5	39	61	
Perch	113	F	397	3/9	4/10	33	51	
Perch	114	F	482	3/16	3/16	1	1	
N. Pike	1006		1588	4/2	4/3	2	4	
Perch	1009	M	284	4/3	4/19	17	32	
Lm. Bass	1011	F	928	4/2	5/22	51	35	
N. Pike	1012	F	3232	4/2	4/27	26	23	
Perch	1013	F	482	4/4	5/12	39	43	
Perch	1014	F	397	4/4	5/4	31	52	
N. Pike	1015	F	1764	4/10	5/2	42	48	103
Perch	1016	F	425	4/11	5/6	26	31	
Perch	1017	F	454	4/10	5/20	41	55	
Perch	1018	F	454	4/10	4/24	15	27	
Perch	1032	F	340	4/12	5/10	29	42	
Perch	1033	M	284	4/12	5/10	19	37	
Walleye	1057	M	709	4/14	4/25	12	9	15
Walleye	1081		482	4/19	5/9	22	28	
Perch	1153	M	312	4/25	5/22	28	23	
Perch	1159	F	567	4/26	5/22	27	18	28
Perch	1183	M	340	4/25	5/22	28	37	
Perch	1214	F	340	5/3	5/21	19	8	
Walleye	1215	M	1247	4/30	5/4	5	4	6
Walleye	1794	F	2495	5/13	5/21	9	10	
Walleye	1800	F	2296	5/13	5/22	10	9	
Walleye	1801	F	2778	5/19	5/21	3	3	

Table 7 . Autumn 1975, fish tagged and data collected.

SPECIES	Id. No.	SEX	Wt. Grms.	Date On (1975)	Date Off (1975)	Track. Perd. (Days)	No. of Loc.	No. of Temperature
Perch	1805	F	397	9/26	10/31	36	29	
Perch	1807	F	425	10/3	10/3	0	0	
Perch	1808		340	10/3	11/15	44	41	
Perch	1810	F	425	10/3	11/7	36	27	
Perch	1812	F	369	10/3	11/14	43	39	
Perch	1813	F	397	10/3	11/19	48	44	
Walleye	1814		1588	10/7	11/20	45	46	
Walleye	1815	F	3190	10/9	11/19	42	39	
Walleye	1816	F	3062	10/9	11/12	35	34	
Perch	1817	F	454	10/9	11/1	24	20	
Perch	1818		340	10/9	11/23	46	44	
Perch	1819	F	397	10/16	10/24	9	9	
Perch	1820	F	340	10/16	12/11	56	51	
Perch	1821	F	340	10/26	11/26	32	29	
Perch	1822	F	482	11/4	11/9	6	5	
Perch	1824	F	397	11/4	12/20	47	41	
Perch	1825	F	510	11/5	12/16	42	20	
Perch	1826	F	482	11/5	12/12	38	35	
Perch	1827	F	482	11/5	12/14	40	35	
Perch	1828		340	11/27	1/1/76	36	25	
Perch	1829	F	340	11/27	12/18	22	19	
Perch	1830	F	340	11/27	1/1/76	36	22	
Perch	1831	F	312	11/27	12/23	27	23	

Table 8 . Winter and early spring 1976, fish tagged and data collected.

Species	Id. No.	SEX	Wt. Grms.	Date On (1976)	Date Off (1976)	Track. Perd. Days	No. of Loc.	No. of Temperature
Walleye	1832		2041	12/10/75	12/13/75	4	3	
Perch	1833	F	482	1/5	3/3	58	40	79
Perch	1834	F	383	1/11	1/30	20	41	130
Perch	1835	F	397	1/17	1/17	0	0	0
Perch	1836	F	454	1/29	5/27	119	39	48
Perch	1837	F	340	1/29	6/2	125	88	1137
Perch	1838	F	383	1/29	4/4	66	53	342
Perch	1839	F	340	1/29	2/25	28	7	24
Perch	1840	F	454	2/3	2/16	14	15	
Perch	1841	F	383	2/3	3/24	50	31	
Perch	1842	F	354	2/8	3/8	29	31	353
Perch	1843	F	369	2/8	3/9	30	22	91
Perch	1844	F	326	2/8	4/13	65	47	45
Perch	1845	F	454	2/21	2/21	1	1	1
Perch	1846	F	482	2/27	5/9	72	29	29
Perch	1847	F	367	2/27	4/20	53	41	62
Perch	1848	F	454	3/25	5/9	46	32	203
Perch	1850	F	567	4/11	4/18	8	12	
Perch	1851	F	482	4/11	6/2	53	37	
Perch	1852	F	482	4/11	5/9	29	38	
Perch	1853	F	425	4/11	6/2	53	30	
Perch	1854	F	425	4/11	5/9	29	26	
Perch	1855	F	397	4/21	6/2	43	18	
Perch	1856	F	425	4/21	5/16	26	17	
Perch	1857	F	412	4/23	4/27	5	5	

Table 9. Autumn 1976, fish tagged and data collected.

SPECIES	Id. No.		Wt. Grms.	Date On (1976)	Date Off (1976)	Track. Perd. Days	No. of Location
Perch	3001	F	369	9/11	9/25	15	12
Perch	3002	F	312	9/10	10/6	27	25
Perch	3003	F	340	9/10	9/17	8	5
Perch	3004	F	340	9/10	10/19	40	34
Perch	3006	F	425	9/10	9/24	15	12
Perch	3007	F	340	9/24	10/21	28	28
Perch	3008	F	312	9/10	9/28	19	16
Perch	3009	F	369	9/11	10/17	37	34
Perch	3010	F	326	9/24	10/27	34	32
Perch	3011	F	340	9/11	10/20	37	40
Perch	3012	F	340	9/11	9/28	18	14
Perch	3013	F	369	9/10	9/17	6	5
Perch	3014	F	369	9/11	11/3	54	48
Perch	3015	F	354	9/12	9/21	10	7
Perch	3016	F	354	9/24	10/31	38	37
Perch	3017	F	312	9/12	9/17	6	5
Perch	3018	F	340	9/16	9/16	0	0
Perch	3020	F	354	9/16	9/24	9	6
Perch	3021	F	326	9/17	10/2	17	14
Perch	3022	F	312	9/17	10/8	22	20
Perch	3023	F	340	10/16	11/12	28	25
Perch	3024	F	369	10/12	11/19	39	30
Perch	3026	F	312	10/12	11/19	39	30
Perch	3027	F	312	10/12	11/24	44	31
Perch	3028	F	298	10/12	10/30	19	19
Perch	3029	F	369	10/16	11/30	46	25
Perch	3030	F	397	10/19	10/19	0	0
Perch	3031	F	284	10/16	11/30	46	25

Table 10. (Continued.) Autumn 1976, fish tagged and data Collected.

SPECIES	Id. No.	SEX	Wt. Grms.	Date On (1976)	Date Off (1976)	Track Perd. Days	No. of Locations
Perch	3031	F	284	10/16	11/30	46	25
Perch	3032	F	298	10/20	11/30	42	35
Perch	3033	F	369	10/16	11/19	35	23
Perch	3034	F	340	10/16	11/30	46	28
Perch	3035	F	369	10/16	11/3	19	17
Perch	3036	F	397	10/20	11/7	19	17
Perch	3039	F	354	10/20	11/30	42	25
Perch	3040	F	284	10/20	11/30	42	35
Perch	3041	F	298	10/20	11/30	42	24
Perch	3042	F	340	10/20	10/20	1	1
Perch	3043	F	284	10/20	11/9	23	19
Walleye	3048		1701	10/16	11/15	31	17
Walleye	3049	F	1361	10/16	11/2	19	17
Perch	3050	F	284	10/23	11/30	39	21
Perch	3052	F	284	11/6	11/30	25	20
Perch	3054	F	284	10/23	11/24	32	31
Perch	3055	F	312	11/6	11/30	25	20
Perch	3056	F	326	11/6	11/30	25	19
Perch	3057	F	354	11/6	11/30	25	14
Perch	3059	F	354	11/6	11/30	25	20
Perch	3060A	F	312	11/6	11/19	14	10
Perch	3060B	F	397	11/6	11/30	25	19
Perch	3063	F	383	11/6	11/30	25	20
Perch	3065	F	383	11/6	11/30	25	17
Perch	3067	F	539	11/6	11/24	18	19
Perch	3068	F	439	11/6	11/30	25	19
Perch	3071	F	397	11/6	11/30	25	20

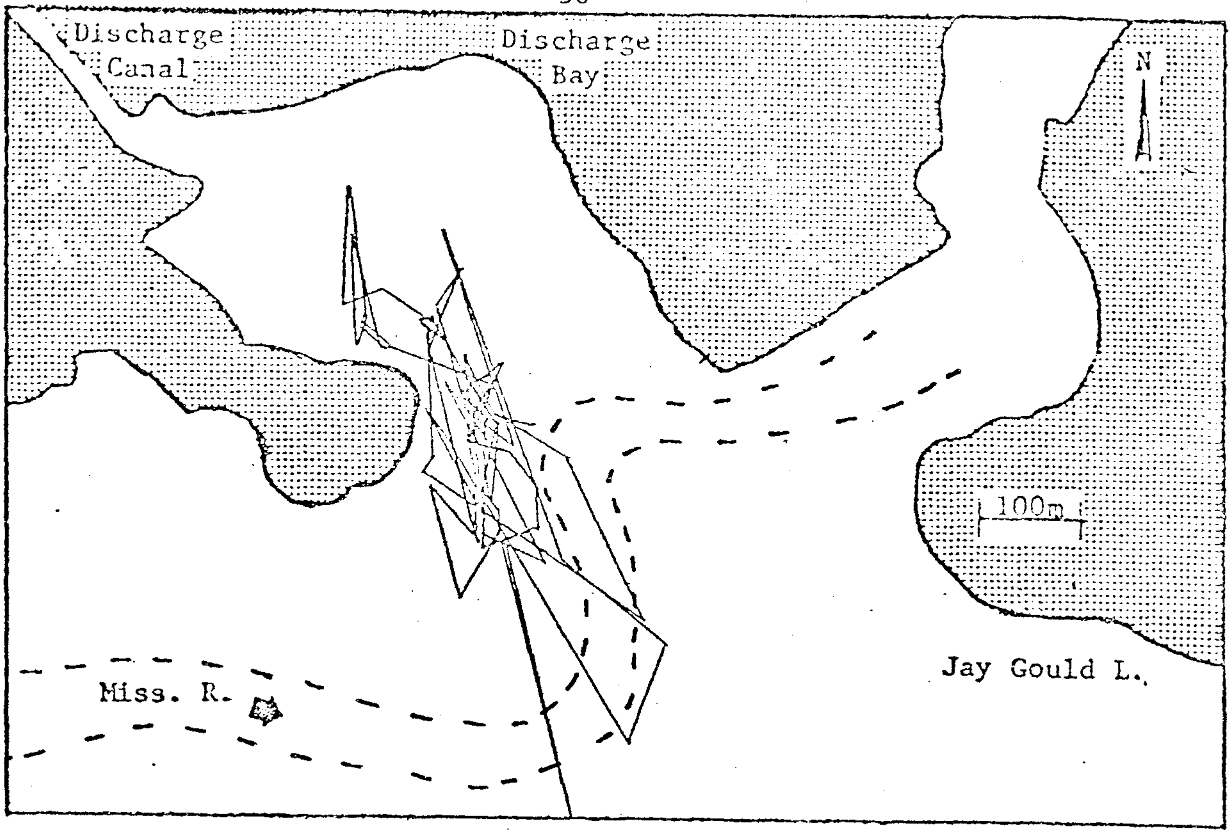


FIGURE 10. Movement pattern of yellow perch no. 107.

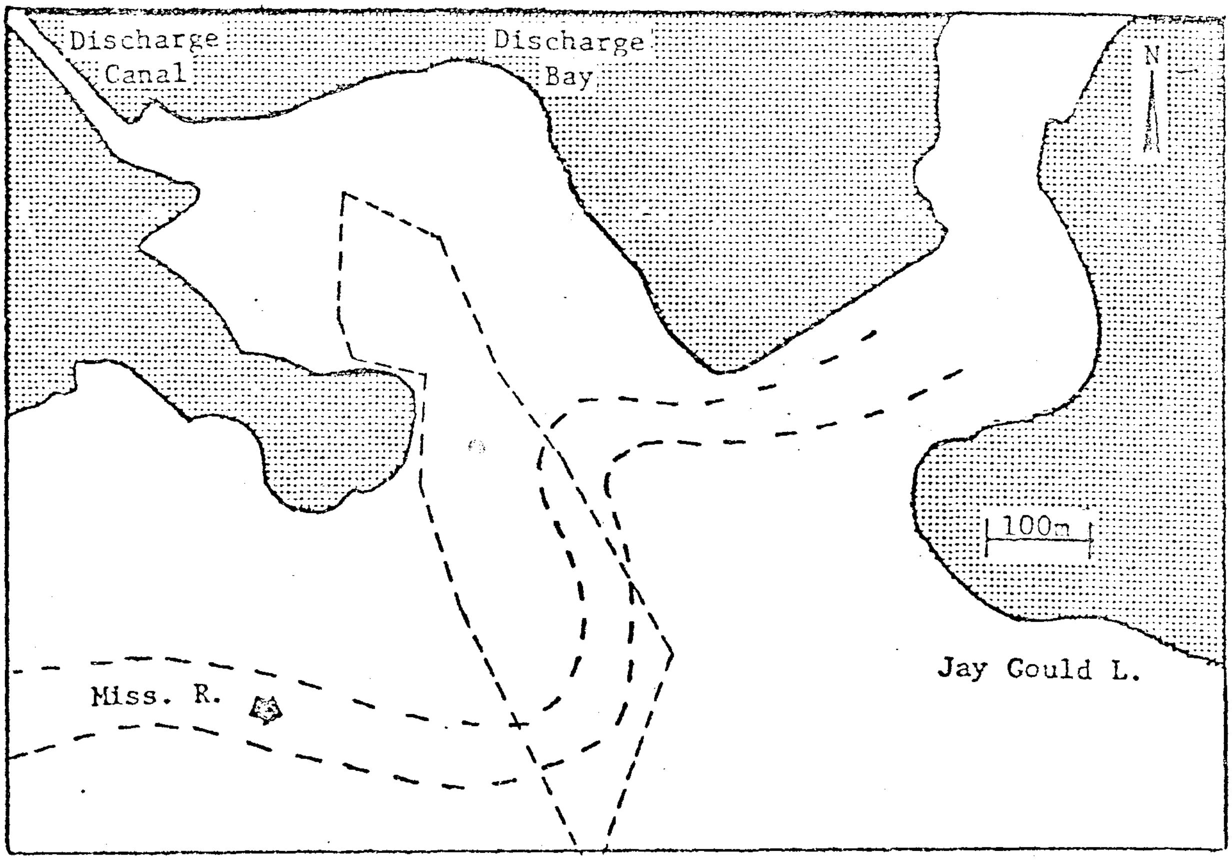


FIGURE 11. Home range of yellow perch no. 107.

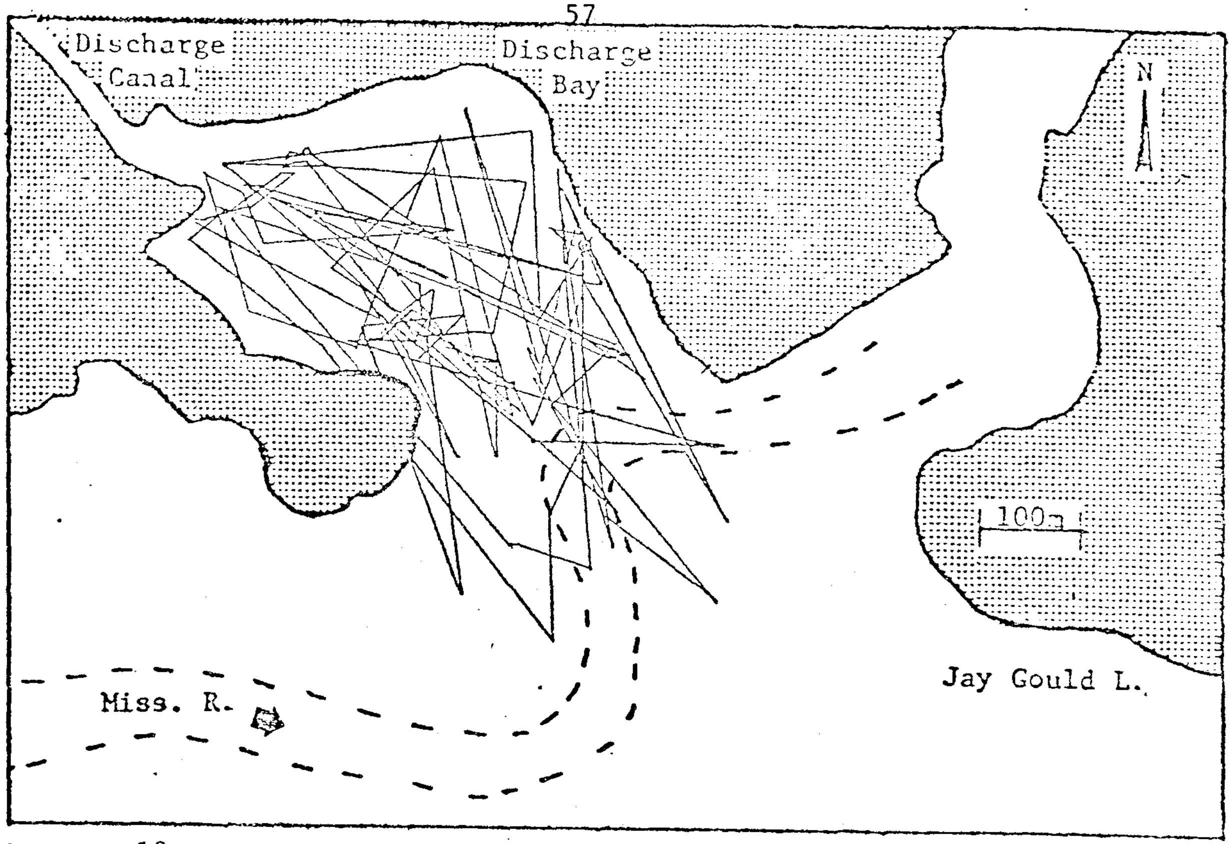


FIGURE 12. Movement pattern of northern pike no. 102.(⊙, capture-release location)

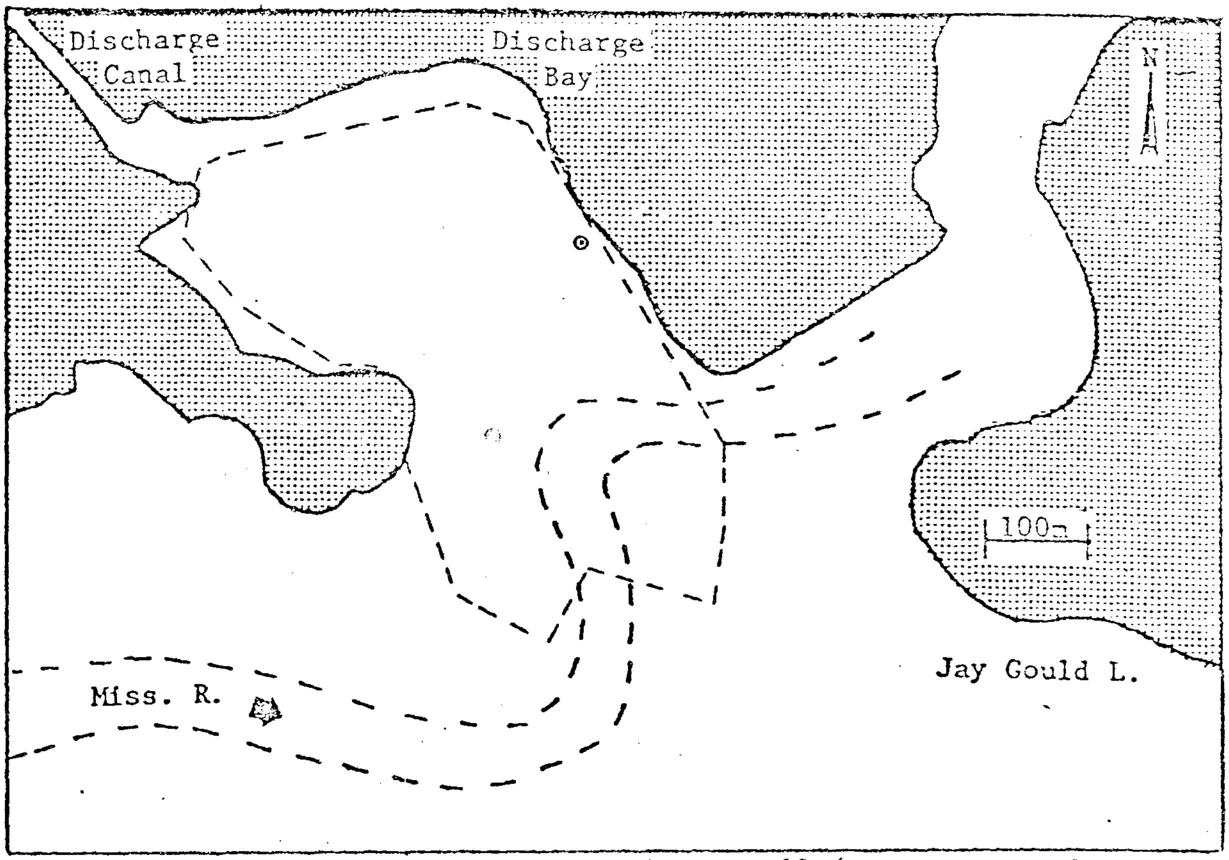


FIGURE 13. Home range of northern pike no. 102.(⊙, capture-release location)

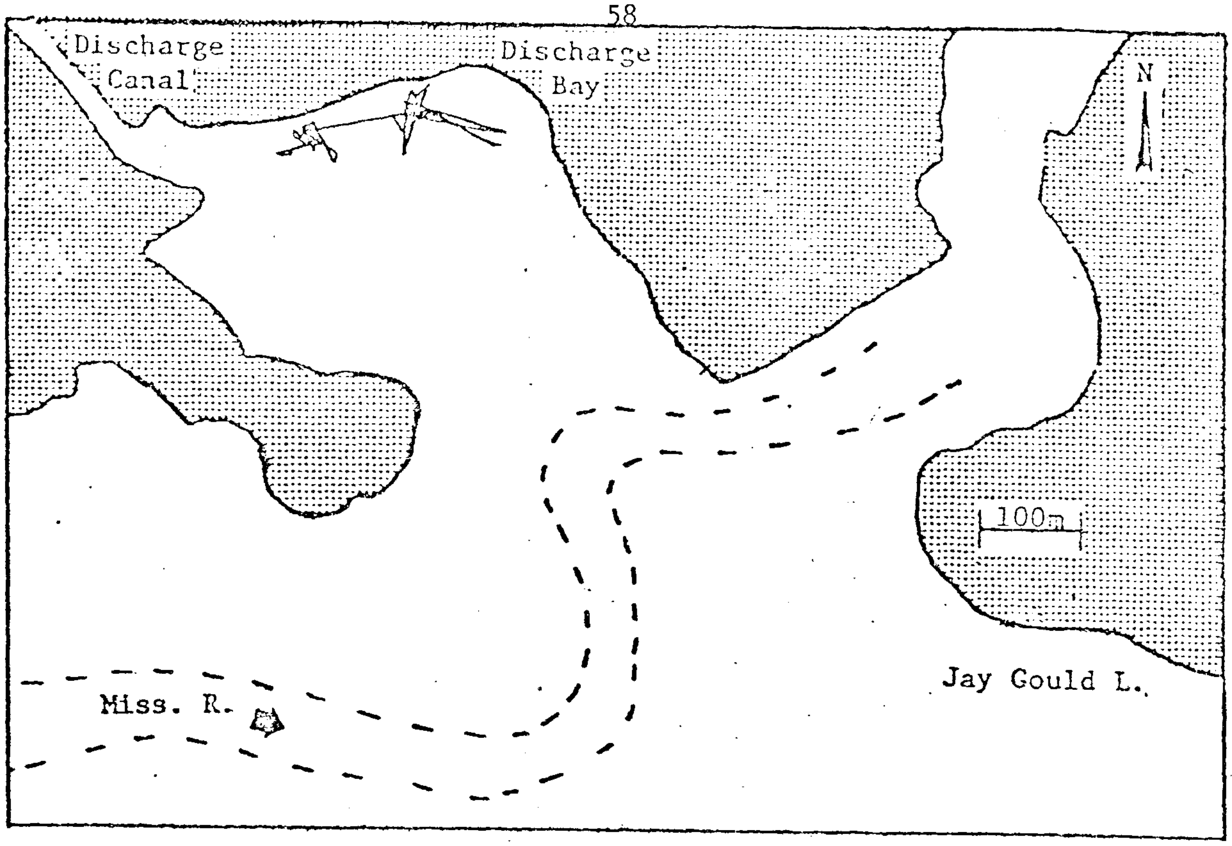


FIGURE 14. Movement pattern of largemouth bass no. 1011. (⊙, capture-release location)

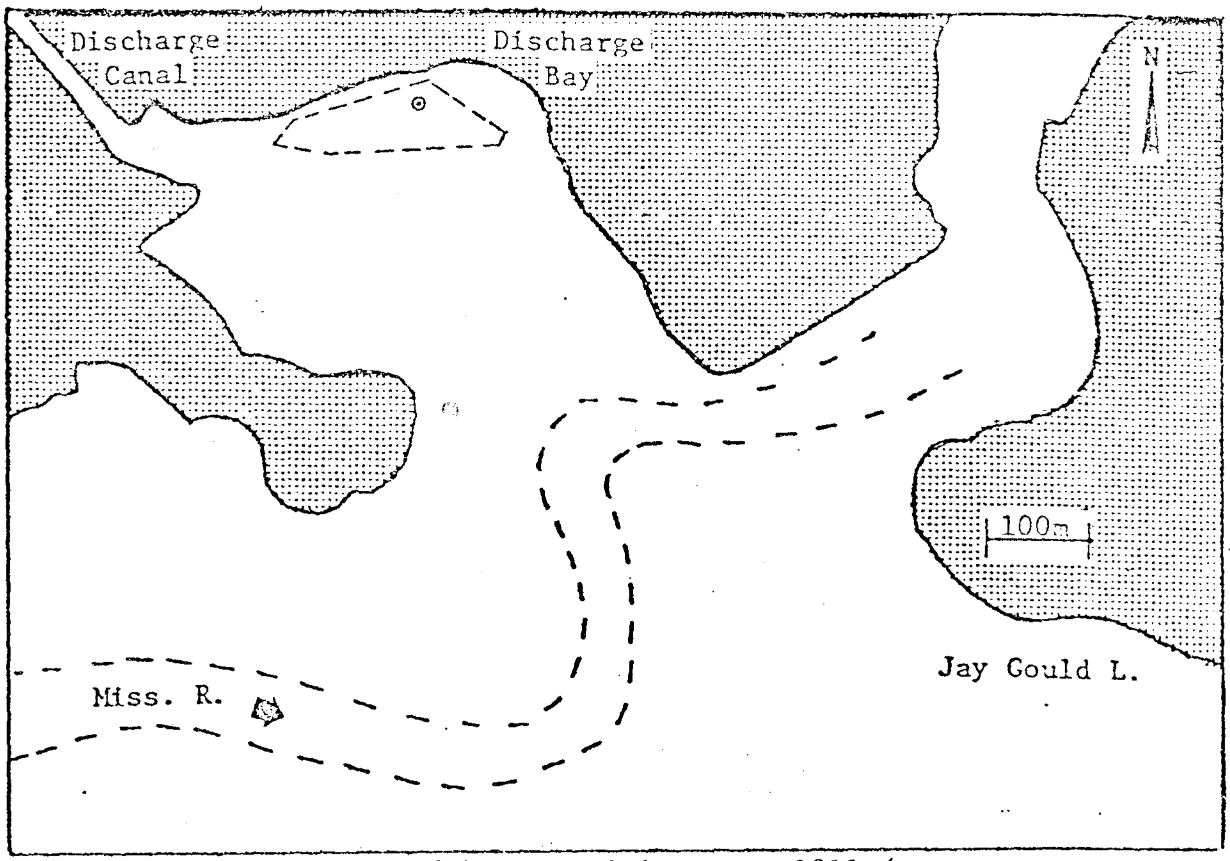


FIGURE 15. Home range of largemouth bass no. 1011. (⊙, capture-release location)

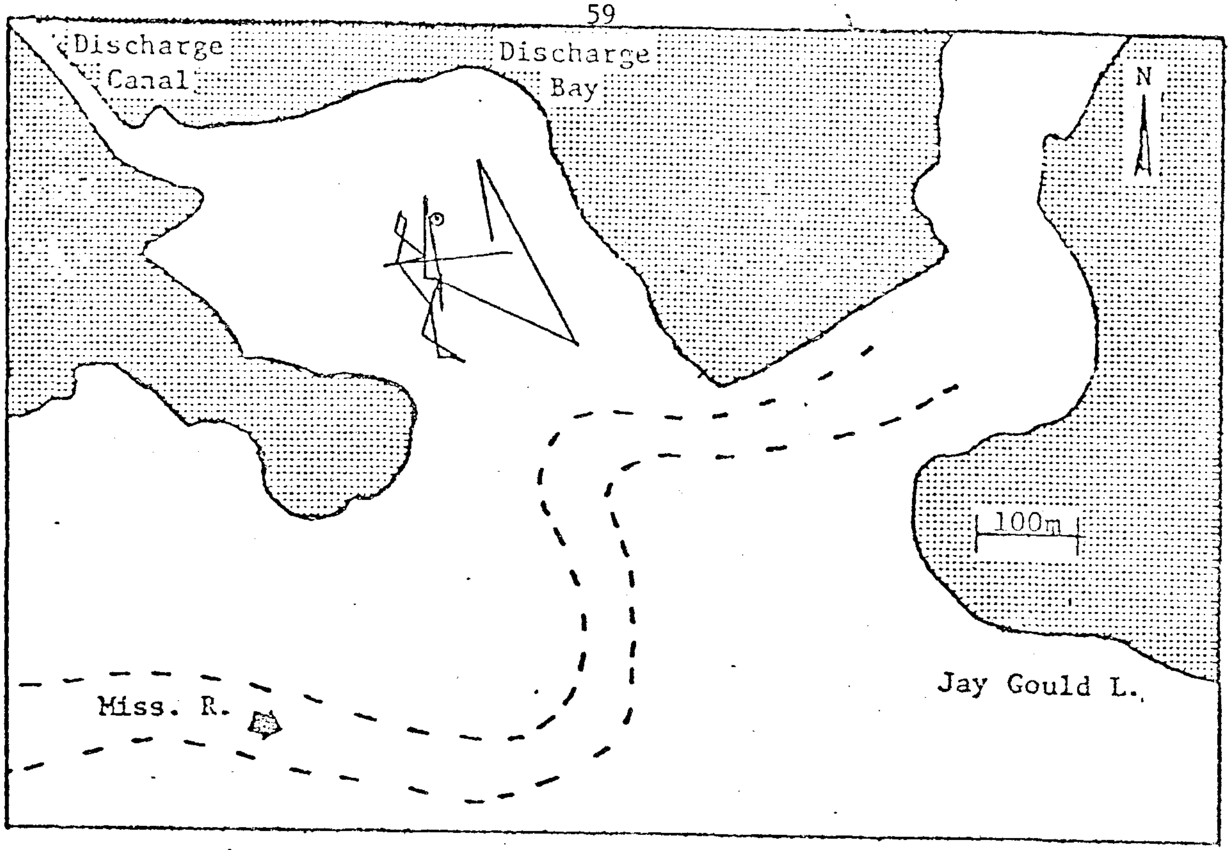


FIGURE 16. Movement pattern of walleye no. 1081. (⊙, capture-release location)

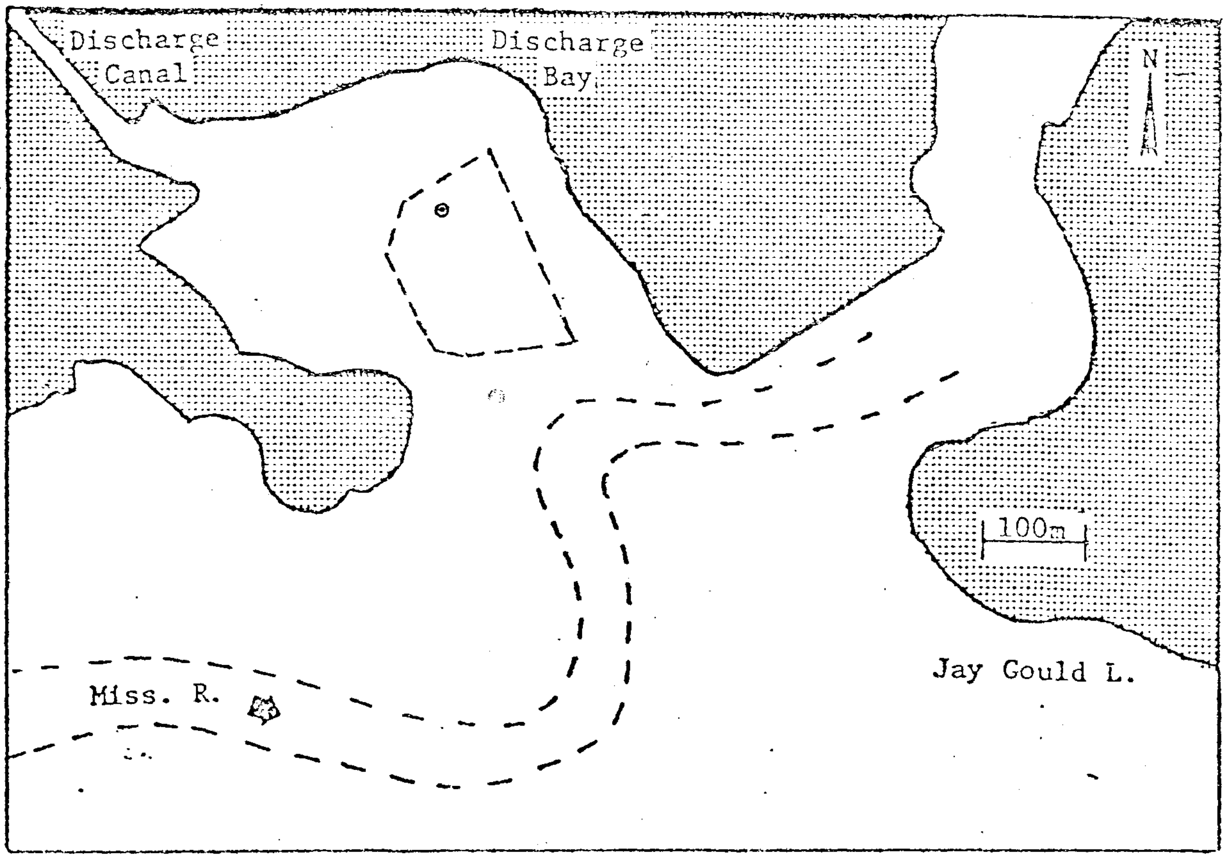


FIGURE 17. Home range of walleye no. 1081. (⊙, capture-release location)

walleye in the vicinity of the thermal discharge. Table 11 presents home range information. Northern pike had the largest mean winter home range size (18.7 ha) followed respectively by yellow perch (10.6 ha), largemouth bass (3.7 ha) and walleye (2.2 ha). However there was a good deal of variability within each group and the number of instrumented individuals was large for only perch.

Mobility

Indices of mobility were determined by considering the distribution of distances between locations and release site, locations and geometric center of the home range, and distance between consecutive locations (Table 12). Northern pike exhibited the greatest mobility with respect to all three parameters. They moved at a daily rate more than double that of bass and walleye. Northern pike and yellow perch moved at a more rapid daily rate and substantially further from the release site and geometric center of their home ranges than the walleye or bass. Figure 18 presents distance from geometric center of home range data at 50 m intervals. Ninety percent of the walleye locations were within 100 m of the geometric center of the home range. Localized movement was also apparent from the largemouth bass frequency distribution. Over 50% of both northern pike and yellow perch locations were further than 100 m from the home range's geometric center.

Temperature

When individual fish locations were mapped over average winter isotherms in upper 1.5 m the discharge bay (Figures 19 to 22), largemouth bass were found in the warmest areas. Yellow perch were generally

Table 11. Adjusted minimum area winter home ranges.

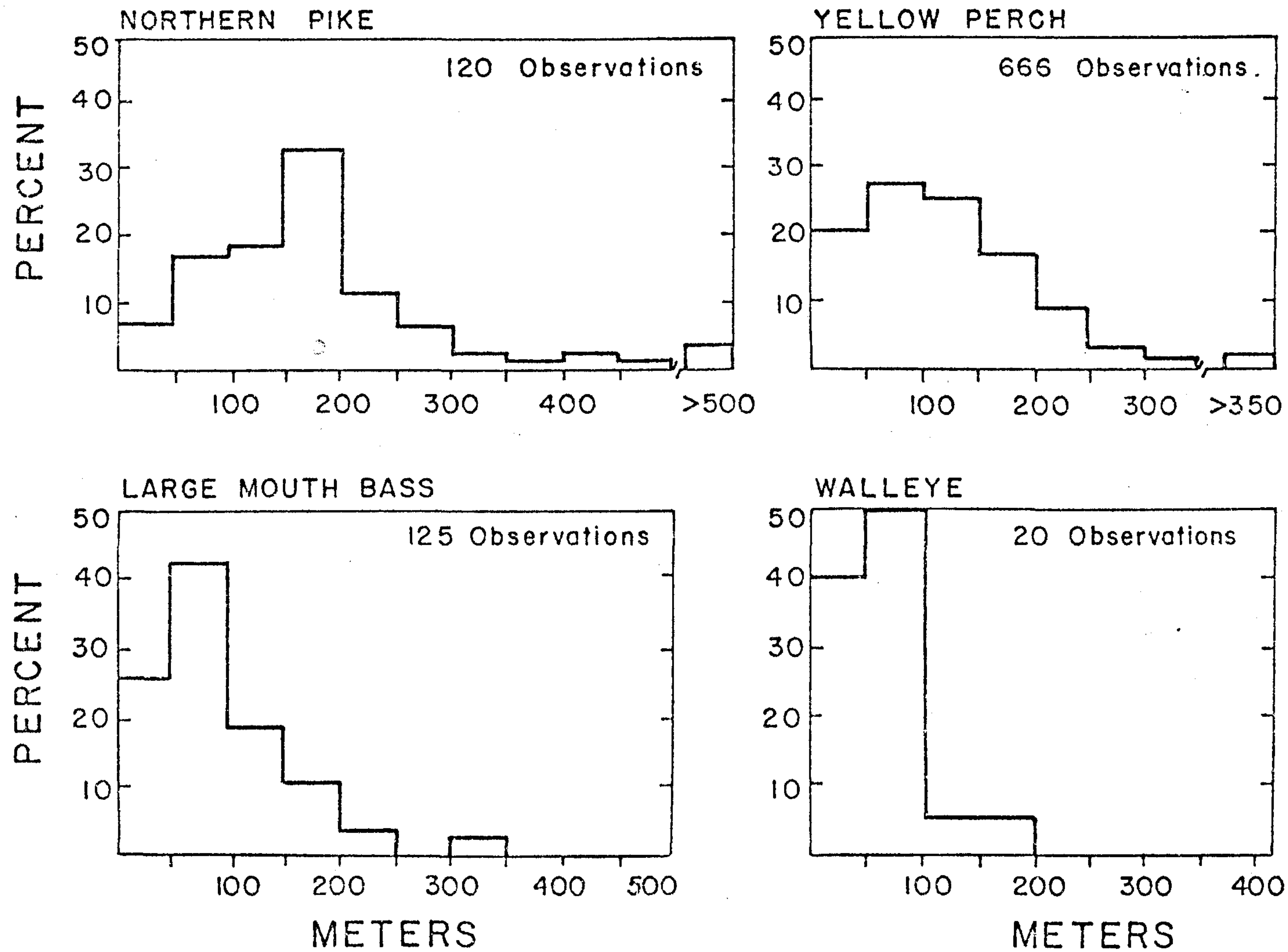
YELLOW PERCH		NORTHERN PIKE		LARGEMOUTH BASS		WALLEYE	
Id.No.	Home Range in ha.	Id.No.	Home Range in ha.	Id.No.	Home Range in ha.	Id.No.	Home Range in ha.
107	8.5	101	11.4	104	7.0	1081	2.2
108	11.4	102	30.8	1011	0.3		
110	17.8	103	15.5				
111	22.0	106	16.5	Mean	3.7		
113	14.0	1012	27.0				
1009	9.1	1015	12.6				
1014	15.4						
1017	13.0	Mean	18.9				
1033	9.2						
1833	5.2						
1834	11.2						
1837	7.3						
1838	13.7						
1840	7.4						
1841	11.0						
1842	6.8						
1843	1.6						
1847	6.0						
Mean	10.6						

Table 12. Fish mobility as mean distance moved per day and mean distance moved from center of home range and release site.

	LARGEMOUTH BASS		WALLEYE		YELLOW PERCH		NORTHERN PIKE	
	Mean Distance	No. Indi-viduals	Mean Distance	No. Indi-viduals	Mean Distance	No. Indi-viduals	Mean Distance	No. Indi-viduals
Mean distance moved from release site (meters).	74	2	75	1	219	19	297	4
Mean distance moved from geometric center of home range (meters).	63	2	59	1	109	19	183	4
Mean distance moved per day (meters).	89	2	91	1	175	14	251	4

Figure 18

Distribution of fish distances from geometric center of home range.


NORTHERN PIKE
120 Observations
YELLOW PERCH
666 Observations.
LARGE MOUTH BASS
125 Observations
WALLEYE
20 Observations
PERCENT
PERCENT
10
20
30
40
50
100
200
300
400
>500
>350
500
METERS
METERS

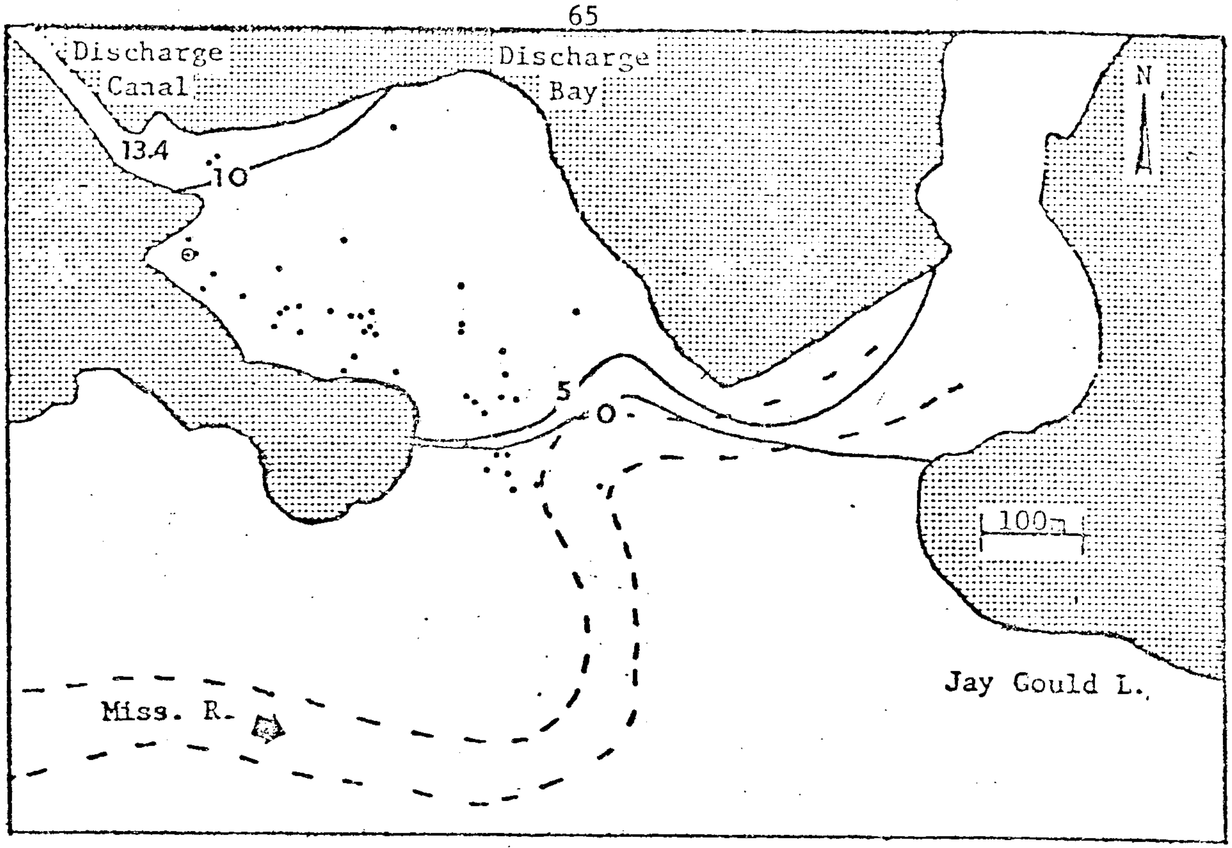


FIGURE 19. Yellow perch no. 113 locations relative to average winter isotherms.(°C).

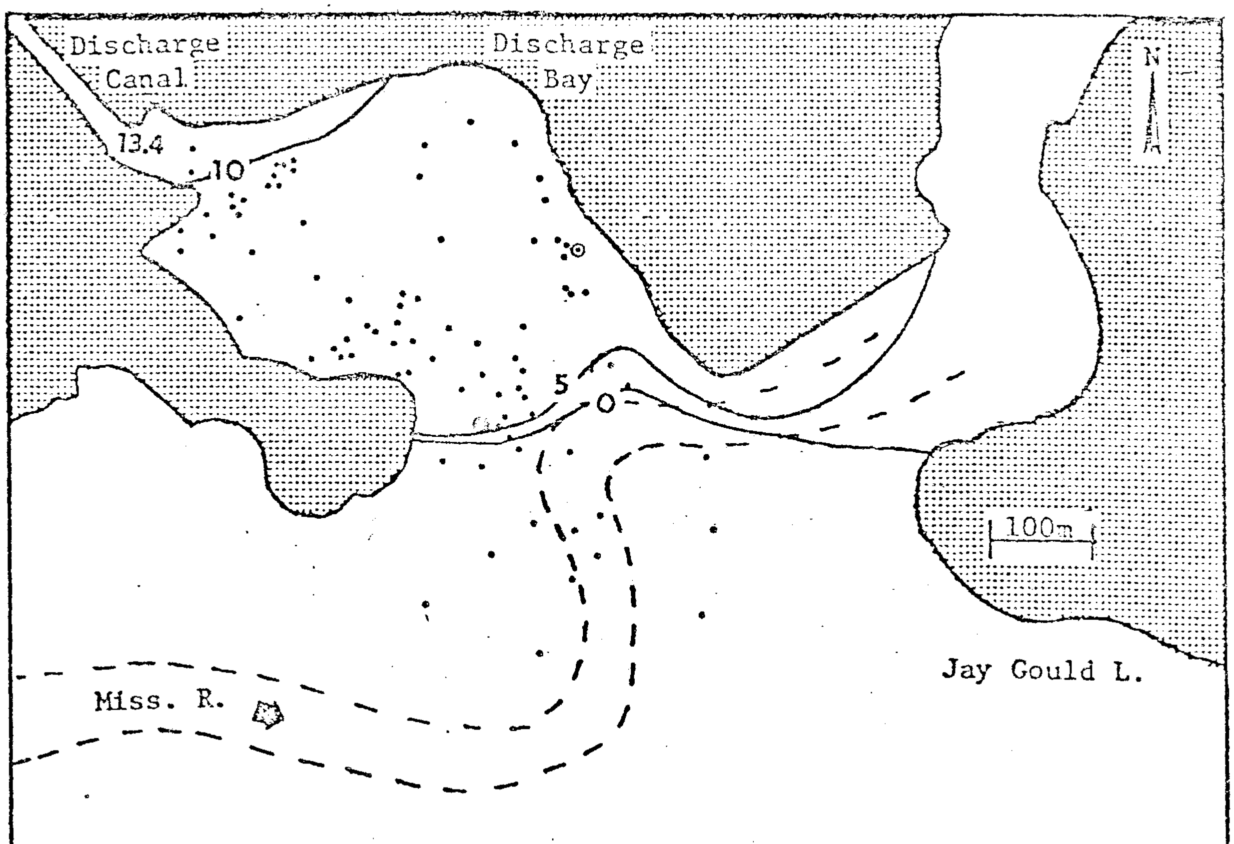


FIGURE 20. Northern pike no. 102 locations relative to average winter isotherms.(°C).

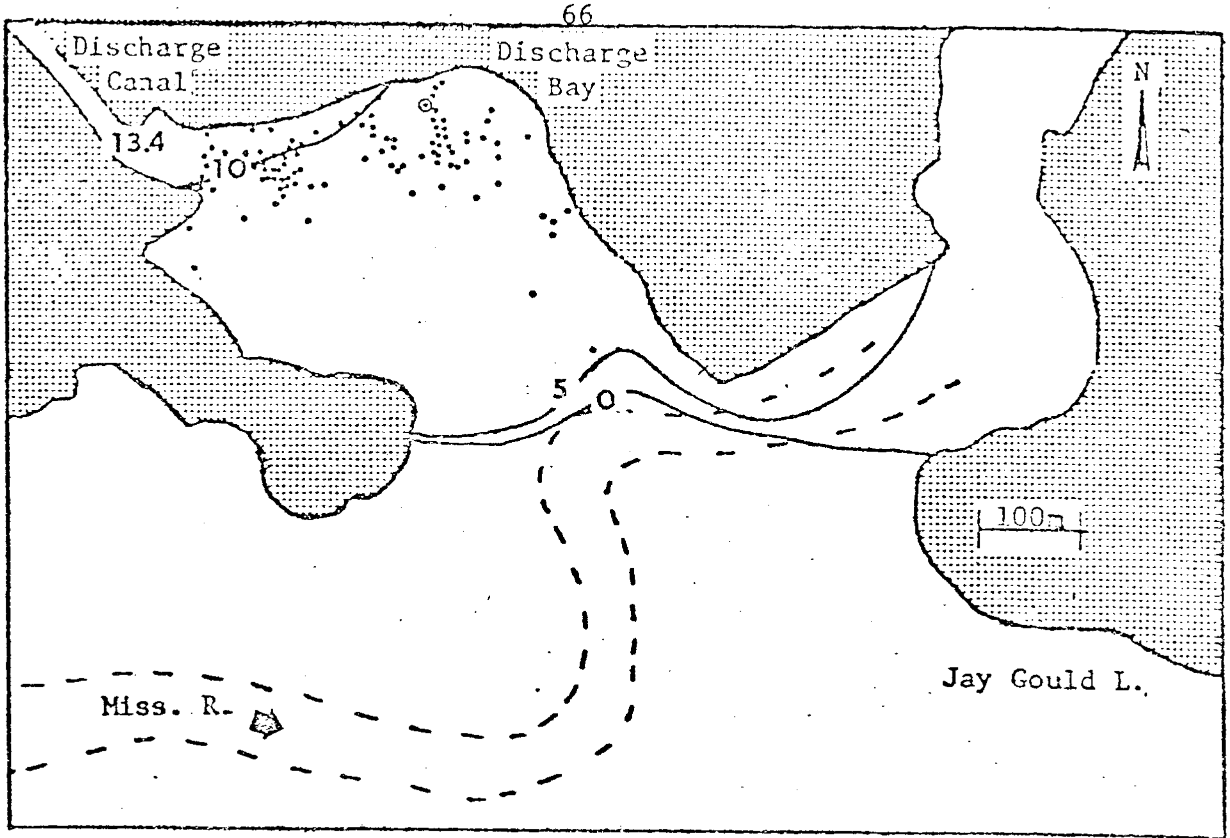


FIGURE 21. Largemouth bass no. 104 locations relative to average winter isotherms. (°C).

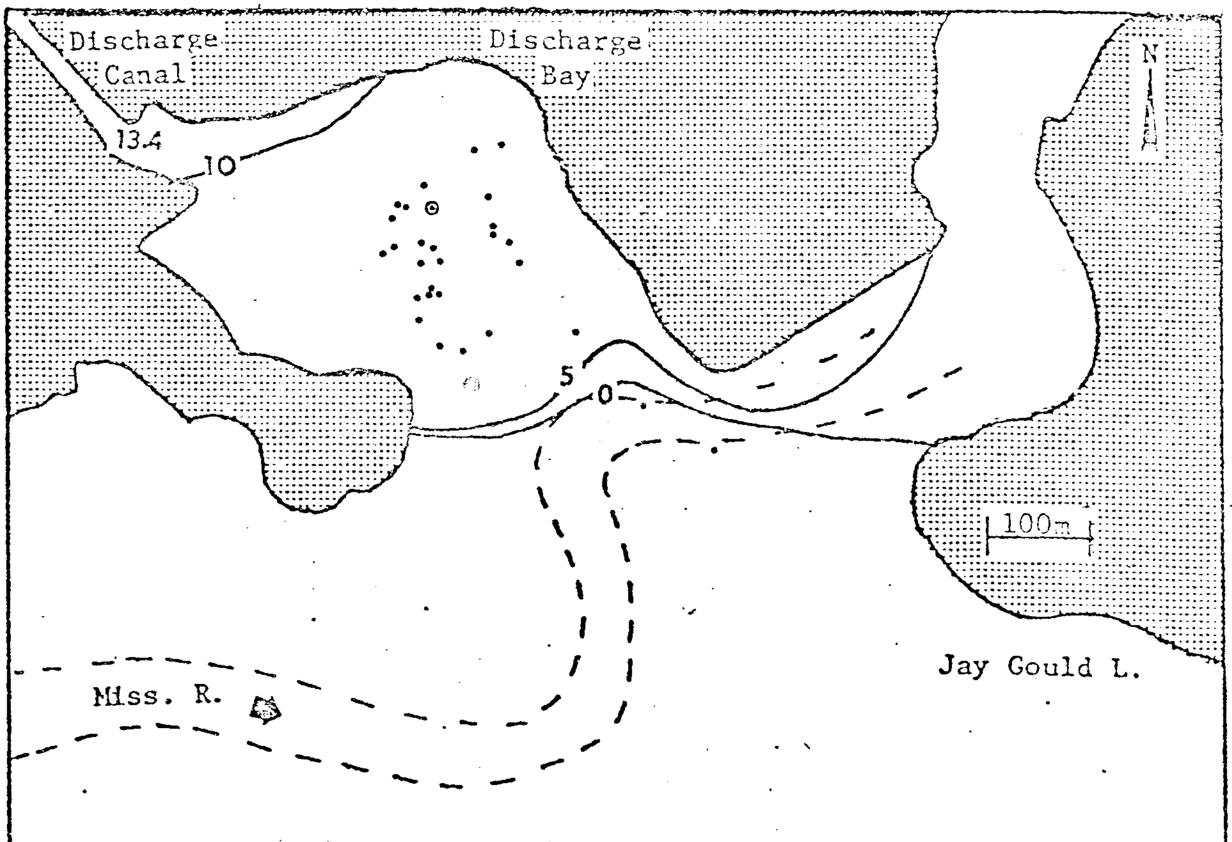


FIGURE 22. Walleye no. 1081 locations relative to average winter isotherms. (°C).

located in intermediate areas and northern pike moved over all discharge affected areas. Mean distance from the discharge was computed for each species (Table 13) and was as follows: largemouth bass, 322 m; perch, 411 m; and northern pike, 411 m. Mean walleye distance for one individual was 404 m,however, a high percentage of these locations were in the center, deeper area of the discharge bay. These areas were considerably cooler than the upper 1.5 m (Figure 23).

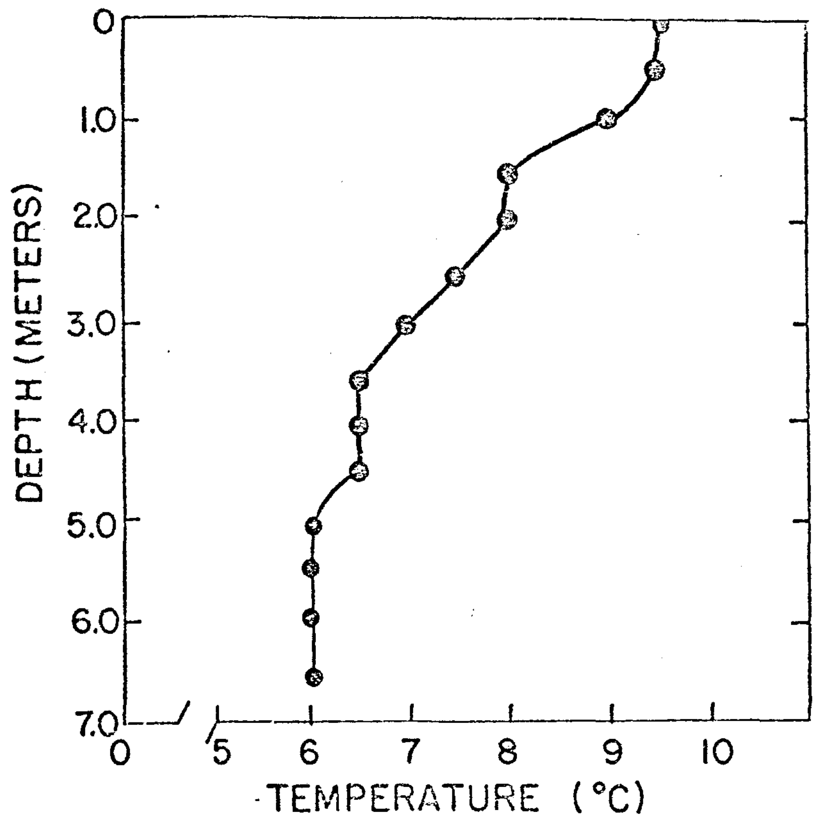
It seemed that variations in power plant operations could have caused changes in thermal discharge temperature which would have resulted in changed fish distribution. Individuals could have maintained a constant temperature by moving closer to or further away from the discharge point depending on the type and magnitude of power plant alteration. Distances from individual perch locations to discharge points were determined for three discharge temperatures: 5^{o}-9^{o}C, 10^{o}-13^{o}C and 14^{o}-18^{o}C. These temperature classes roughly corresponded respectively to one unit operating, both units operating less than full capacity and both units operating full capacity. Limited location data were available because when temperature transect data were being collected,fish tracking data were not taken. However, 36 perch locations obtained within 24 hours of monitoring a discharge temperature between 5^{o}C and 9^{o}C were a mean distance of 467 m from the discharge point. Likewise, eight perch locations obtained at discharge temperatures between 10^{o}C and 13^{o}C were found to average 341 m from the discharge point. Sixty-four locations obtained at discharge temperatures between 14^{o}C - 18^{o}C were determined to be a

Table 13. Mean fish distance from discharge point (meters).

YELLOW PERCH		NORTHERN PIKE		LARGEMOUTH BASS		WALLEYE	
Id.No.	Mean Distance	Id.No.	Mean Distance	Id.No.	Mean Distance	Id.No.	Mean Distance
107	537	101	556	104	229	1081	404
108	438	103	311	1011	345		
110	489	106	307	MEAN	322		
111	424	1012	471				
113	368	MEAN	411				
1009	429						
1014	381						
1017	432						
1033	342						
1183	433						
1833	393						
1834	299						
1837	465						
1838	428						
1840	290						
1841	459						
1842	483						
1843	470						
1847	254						
MEAN	411						

Figure 23.

Discharge area mean winter water temperatures vs. depth.



DEPTH (METERS)
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0
5
6
7
8
9
10
TEMPERATURE (°C)

mean distance of 384 m from the discharge point. Analysis of variance showed these means were not significantly different (P = .05) and there was no apparent pattern to perch distribution with respect to alteration in plant operations.

Tables 14 and 15 present results for fish movement between thermally modified and unaltered waters. Nineteen of 31 winter perch crossed between altered and unaltered waters at least one time while in the vicinity of the thermal discharge during the winter months. Eighteen of 31 perch dispersed from the discharge bay during winter months. Only 2 of 31 perch remained entirely within thermally altered areas during the winter tracking period. Eight perch exhibited crossing and eventually dispersed. Eight additional perch were tracked after the peak of spawning in April 1976. All fish in this group dispersed from the discharge bay within 16 days after tagging. Of the 26 perch observed to disperse from the discharge bay,58% moved upstream,35% moved downstream and 8% moved into unaltered areas of Jay Gould Lake.

All northern pike tracked for more than 4 days moved between discharge and unaltered waters. Three individuals crossed and 3 exhibited both crossing and disperal behavior. All 3 winter walleyes tracked also moved between altered and unaltered waters. One individual crossed 7 times. The remaining 2 walleyes exhibited both crossing and dispersal behavior. Both largemouth bass remained entirely within the discharge bay during winter months. The average number of crossings per individual for each species were: northern pike 8.5, perch 3.9, walleye 3.7, and largemouth bass 0.

Table 14. Fish movement with respect to thermally altered and unaltered areas.

Id. No.	Cros- sings	Dispersal Date	DISPERSAL LOCATION River Downstream	River Upstream	Jay Gould Lake	Season & Year
YELLOW PERCH						
107	8					Winter 1975
108	7					
109	8	3/15/75	X			
110	22					
111	4					
113	10	4/6/75	X			
1009	2					
1013	0	4/24/75	X			
1014	12					
1016	4	4/27/75	X			
1017	10					
1018	4	4/24/75	X			
1032	6	5/10/75		X		
1033	2					
1153	2	4/29/75		X		
1159	2	5/4/75		X		
1183	9					
1833	0	1/20/76		X		Winter 1976
1834	0					
1836	0	2/16/76		X		
1837	0	3/26/76	X			
1838	0	3/23/76		X		
1839	0	2/25/76		X		
1840	0					
1841	3	2/28/76	X			
1842	0	2/25/76		X		
1843	6					
1844	0	2/21/76	X			
1846	0	2/27/76		X		
1847	2					
1848	0	4/7/76			X	
1850		4/18/76	X			Spring 1976
1851		4/26/76		X		
1852		4/23/76		X		
1853		4/18/76		X		
1854		4/15/76		X		
1855		4/15/76		X		
1856		4/21/76		X		
1857		4/24/76			X	

Table 15. (Continued.) Fish movement with respect to thermally altered and unaltered areas.

Id. No.	Cros-sing	Dispersal Date	DISPERSAL LOCATION River Downstream	River Upstream	Jay Gould Lake	Season & Year
NORTHERN PIKE						WINTER 1975
101	6					
102	26	4/6/75		X		
103	5					
106	4					
1012	2	4/27/75			X	
1015	6	4/27/75	X			
WALLEYE						
100	7					
1057	2	4/15/75		X		
1081	2	5/9/75		X		
LARGEMOUTH BASS						
104	0					
1011	0					

The high percentage of fish, other than largemouth bass, observed crossing between thermally modified and unaltered areas, and the large numbers of perch, northern pike and walleye observed dispersing from the discharge bay implied that the thermal experience was generally transitory. This was further substantiated by looking at the number of days an individual was located in or near the discharge area as a percent of the total period the fish was tracked. For the purposes of this analysis fish that briefly crossed into nearby unaltered waters and returned to the discharge bay were counted as discharge area fish. Table 16 presents these results. The percent column may appear deceptive. Many of the fish with relatively short tracking periods remained near the discharge area. However, a strong bias toward discharge area locations existed because all fish were captured and released in the discharge bay. Further, tracking periods could only extend to the life of the transmitter. If thermal experience was transitory, a better indicator should have been found by limiting the analysis to those fish that were tracked for protracted time periods. Only one of three northern pike tracked for longer than a month remained near the discharge area. Similarly, 4 of 14 perch tracked for more than 31 days remained near the discharge bay. Although the longest tracking period for a walleye was 22 days none of the three individuals remained entirely in the discharge area.

Depth

Selected individual fish locations mapped over depth contours are depicted in Figures 24 to 27 and summarized in table 17. A chi-square test showed the species distributions to be significantly different

Table 16. Amount of time fish were located in the discharge bay as a percent of the entire individual tracking periods.

YELLOW PERCH				YELLOW PERCH				NORTHERN PIKE			
I.D. No.	Days Tracked	Days in discharge	Percent in discharge	I.D. No.	Days Tracked	Days in discharge	Percent in discharge	I.D.No.	Days Tracked	Days in discharge	Percent in discharge
107	28	28	100%	1833	58	15	26%	102	89	53	60%
108	33	33	100%	1834	20	20	100%	103	31	31	100%
109	38	20	53%	1836	119	17	14%	106	15	15	100%
110	26	26	100%	1837	125	56	45%	1012	26	25	96%
111	38	38	100%	1838	66	25	38%	1015	42	18	43%
113	33	29	88%	1839	28	27	96%	101	43	43	100%
1009	17	17	100%	1840	14	14	100%				
1013	39	21	54%	1841	50	25	50%				
1014	31	31	100%	1842	29	17	59%	WALLEYE			
1016	26	17	65%	1843	30	30	100%	100	10	6	60%
1017	41	41	100%	1844	65	13	20%	1057	12	1	8%
1018	15	14	93%	1846	72	1	1%	1081	22	21	95%
1032	29	28	97%	1047	53	53	100%				
1033	29	19	66%	1848	13	13	28%	LARGEMOUTH BASS			
1153	28	4	14%								
1159	27	8	30%					104	60	60	100%
1183	28	28	100%					1011	51	51	100%

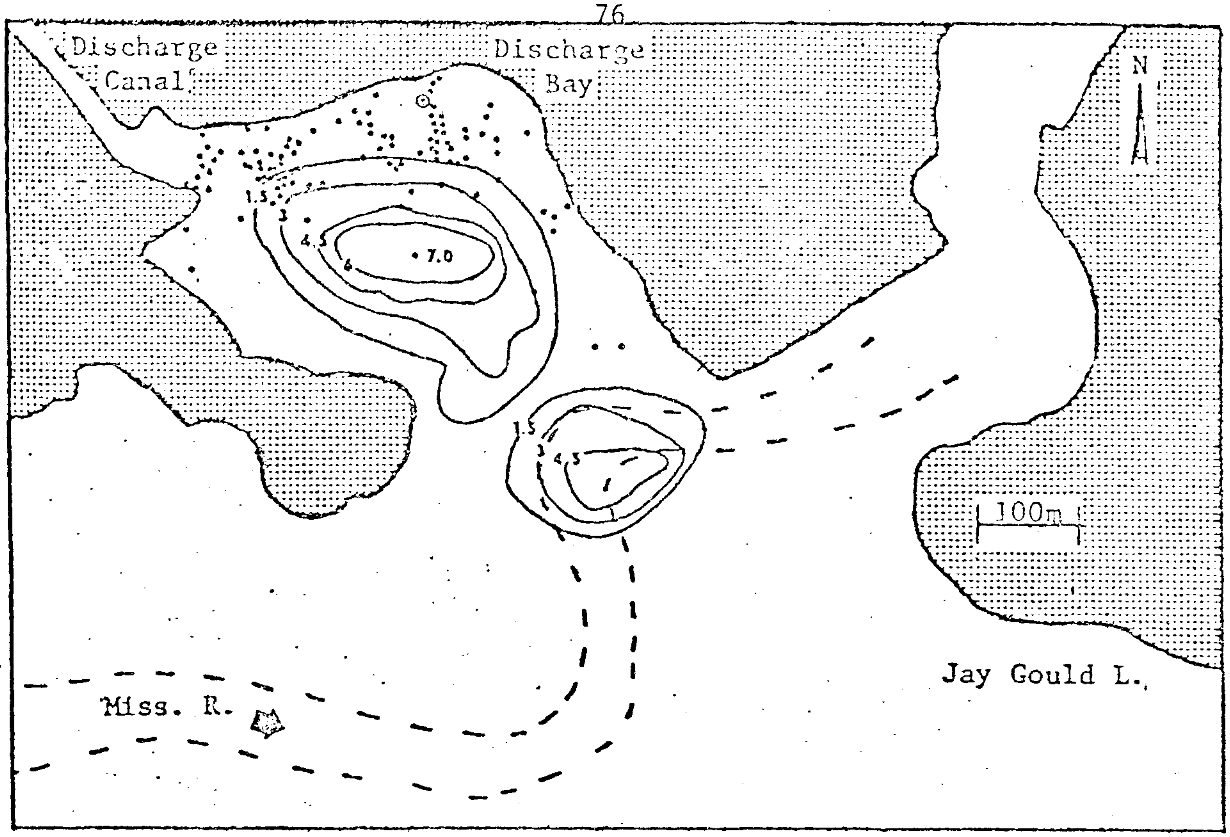


FIGURE 24 . Largemouth bass no. 104 locations relative to depth.

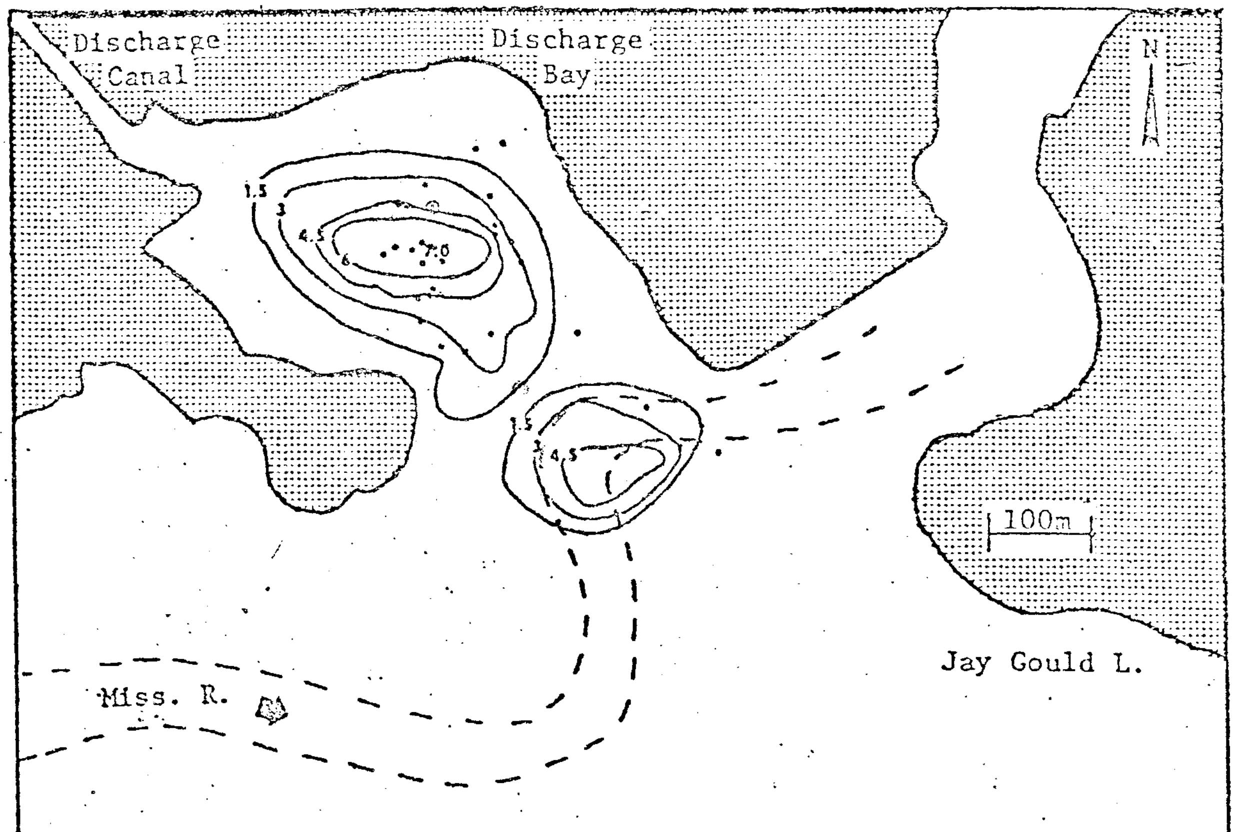


FIGURE 25 . Walleye no. 1081 locations relative to depth.

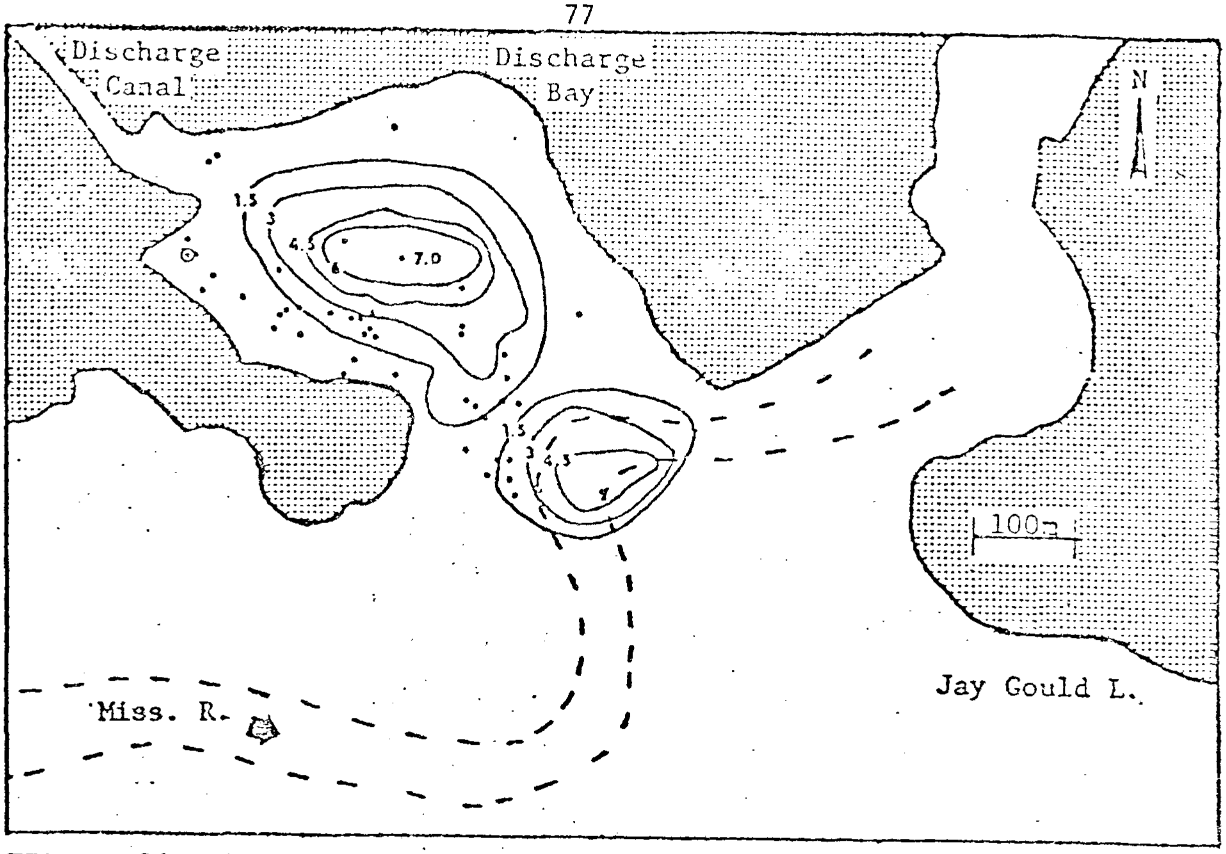


FIGURE 26. Yellow perch no. 113 locations relative to depth.

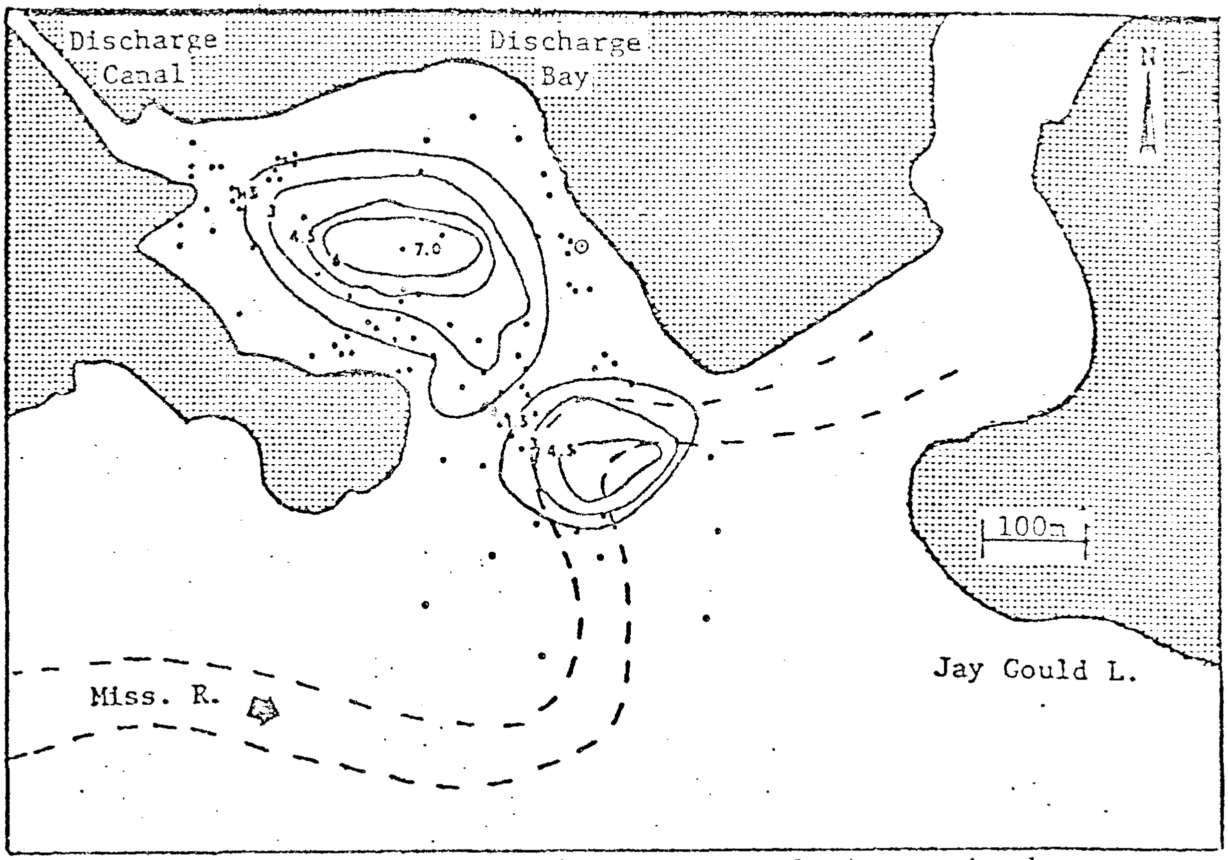


FIGURE 27. Northern pike no. 102 locations relative to depth.

Table 17. Depth selection by fish in the discharge area.

	PERCH		NORTHERN PIKE		LARGEMOUTH BASS		WALLEYE	
Depth	No. of Observations	Percent	No. of Observations	Percent	No. of Observations	Percent	No. of Observations	Percent
0.0-1.5m	541	71%	154	78%	130	96%	7	24%
1.5-3.0m	122	16%	34	17%	5	3%	5	17%
> 3.0 m	97	13%	10	6%	1	1%	17	59%
χ^2	3.2		7.7		32.6		74.9	
TOTAL Chi-Square Value: 118.4								

(P = .05). Largemouth bass selected significantly shallower, near shore, areas than other fish. For example, 95% of all largemouth bass locations were found at a depth less than 1.5 m. Walleyes selected substantially deeper areas because 58% of all walleye locations were found in center areas of the discharge bay which were greater than 3 m deep. Northern pike and yellow perch were intermediate with respect to depth selection. They prefered shallow areas, but, not to the extent of largemouth bass.

Simultanious Tracking

There may have been some bias in comparing species that were not tracked during the same time periods or were tracked considerably longer than others. Therefore an attempt was made to isolate this bias. Table 18 presents summary results for two time intervals when fish of various species were tracked over similar time periods. First one largemouth bass, one northern pike and two perch tracked in late February and March were compared. We selected the least mobile northern pike and most mobile largemouth bass; a worst case situation, to determine if relative distribution results were consistent with overall estimates. In general, the results compared favorably with overall distribution results. Largemouth bass had the smallest home range, least mobility, fewest crossings and shallowest depth distribution closest to the discharge. Perch were intermediate with respect to home range size and mobility. Northern pike and perch crossed into unaltered waters and preferred somewhat deeper areas which were further from the discharge than largemouth bass.

A second period from April 12 to May 4, 1975 was selected to

Table 18. A summary of results for two periods when fish were tracked concurrently.

Species	I.D.No.	Tracking Period: No. Days	Tracking Period: No. Locations	Home Range (hectares)	MOBILITY: Daily movement rate (meters/day)	MOBILITY: Distance from Release (meters)	MOBILITY: Distance moved from Geometric Center of home Range (meters)	Distance from Discharge (meters)	Crossings	DEPTH: 0.0-1.5 (meters)	DEPTH: 1.5-3.0 (meters)	DEPTH: > 3.0m (meters)
F E B R U A R Y 26 T O M A R C H 22, 1975												
YELLOW PERCH	107	25	55	8.5	230	312	112	534	8	35	1	3
	108	25	51	11.4	221	268	125	437	5	33	3	13
	$\overline{X}$	25	53	9.9	226	290	119	495	7	34	2	8
NORTHERN PIKE	103	16	32	14.1	237	365	174	306	2	30	1	1
LARGEMOUTH BASS	104	25	48	3.3	132	123	99	279	0	46	2	0
A P R I L 12 TO M A Y 4, 1976												
YELLOW PERCH	1017	23	38	12.4	215	152	114	432	10	16	11	9
	1033	20	38	9.1	203	123	103	342	2	30	4	4
	$\overline{X}$	22	38	10.8	209	138	109	387	6	23	8	7
WALLEYE	1081	18	23	2.5	73	74	64	409	0	5	2	16

compare walleye and perch distribution parameters. Here again, perch preferred areas away from the discharge point, exhibited more mobility, had greater home range sizes and selected depths shallower than the walleye.

When mid-winter perch from the first time period were compared to the late winter individuals, the only parameters noticeably different were distance from release and discharge. Home ranges, mobility, depth selection and movement between altered and unaltered waters appeared to be similar.

Summary

Comparative species distribution results must be interpreted with a certain degree of caution. Obviously, a larger number of fixes over a protracted time period could have resulted in larger home ranges, more crossings, higher daily movements, etc. The tracking period was determined by transmitter life as determined by the battery size an individual could carry. Also, fish were tracked over noncoincidental time intervals on an irregular schedule. However, each time fish were tracked we attempted to locate all individuals regardless of species which minimized bias.

The nature of telemetry limits the number of individuals that can be tracked at a given time; thus, fish had to be grouped without regard to size or sex. All data analyzed were from adult fish, grouped by species and season. The inclusion of data from different size fish and both male and female fish probably accounted for a portion of the variability blurring interspecific differences. The overall results however, agreed with those obtained in more limited analysis on selected data from periods when the species were tracked concurrently.

Depth was inferred from location as radio tags did not transmit depth data per se. Conceivably, an individual fish could have been at any depth in the water column at a given location, but as Holt et al. (1977) pointed out, walleyes are a demersal species and the probability that this species is near the bottom at any given time is high. Erikson (1975) found that during the winter *Perca fluviatilis* (a closely related European perch species) remained at the bottom of a laboratory tank. Therefore, this method for determining comparative depth data was likely valid for these species.

In general, perch were found to have a home range size less than northern pike and greater than largemouth bass and walleye. Perch preferred shallow areas distal from the discharge point. A high percentage of the individuals I tracked either crossed between the discharge bay and unaltered waters, or dispersed from the discharge bay. Perch mobility as measured by distance moved from the center of home range and from the release site and daily movement rates was determined to be less than northern pike and greater than walleye or largemouth bass. Perch locations showed no difference that could be related to changes in plant operations.

Northern pike generally exhibited the largest mean home range and were the only species to have a mean home range size larger than the discharge bay. This species also preferred relatively shallow areas. Northern pike locations showed the greatest variability with respect to distance from the discharge and were found to virtually cover the discharge bay. Northern pike demonstrated the most mobility and crossed between thermally altered and unaltered waters more often than any other species. No northern pike tracked for more than four days remained entirely in the discharge bay.

Largemouth bass had a small home range and preferred significantly shallower areas closer to the discharge than northern pike or yellow perch. Largemouth bass movements from the center of home range, release site and daily movement rates were determined to be substantially less than those of northern pike and yellow perch. The two largemouth bass remained entirely within thermally altered areas during their tracking periods.

Limited data are available on walleye as only one individual was successfully tracked while maintaining a home range in the discharge bay. This fish had a small home range in the center deep area of the discharge bay. Mobility was less than that of perch and northern pike. All three walleyes tracked during winter months moved between thermally altered and unaltered areas. Two individuals dispersed shortly after instrumentation.

YELLOW PERCH TEMPERATURE RESULTS

Yellow perch winter temperature results indicated a high degree of variability among individuals and no significant diel difference within individuals was detected. Table 19 presents overall perch winter temperature data. Mean temperature selection ranged from 1.1°C to 9.2°C for 10 individuals. Analysis of variance indicated a significant difference among average temperature data for individual perch

Table 19. Overall yellow perch winter temperature selection (degrees celsius).

Id. No.	No. of Observations	Mean	Standard Deviation	Minimum	Maximum	95% Confidence Interval
1833	97	3.4	2.6	0	9.3	2.9 - 4.0
1834	160	5.0	3.0	0	12.8	4.5 - 5.5
1836	23	5.0	3.0	0	8.6	3.8 - 6.4
1837	1110	7.4	2.2	0	13.0	7.3 - 7.5
1838	342	4.8	2.9	0	12.9	4.5 - 5.1
1842	353	6.6	2.6	0	14.4	6.3 - 6.9
1843	92	1.1	1.8	0	10.1	0.7 - 1.5
1844	38	2.5	2.5	0	8.8	1.6 - 3.3
1847	29	9.2	4.3	0	14.6	7.6 - 10.9
1848	121	8.5	2.6	0	14.1	8.1 - 9.0
Total	2365					

Mean by averaging individual means: 5.4°C

Mean by grouped data: 6.3°C

($p > .05$). Table 20 presents the results of three different multiple comparison tests to separate significant groups of means. The least significant difference procedure was considered a liberal test and indicated that the 10 perch winter temperature means with 20 or more observations per individual could be separated into 7 different groups. The more conservative Student-Newman-Kuels' procedure also separated the individual means into 7 groups, while the 'Scheffe' procedure, a very conservative test, divided the individual overall winter means into 6 subsets with a maximum of 4 fish in a group.

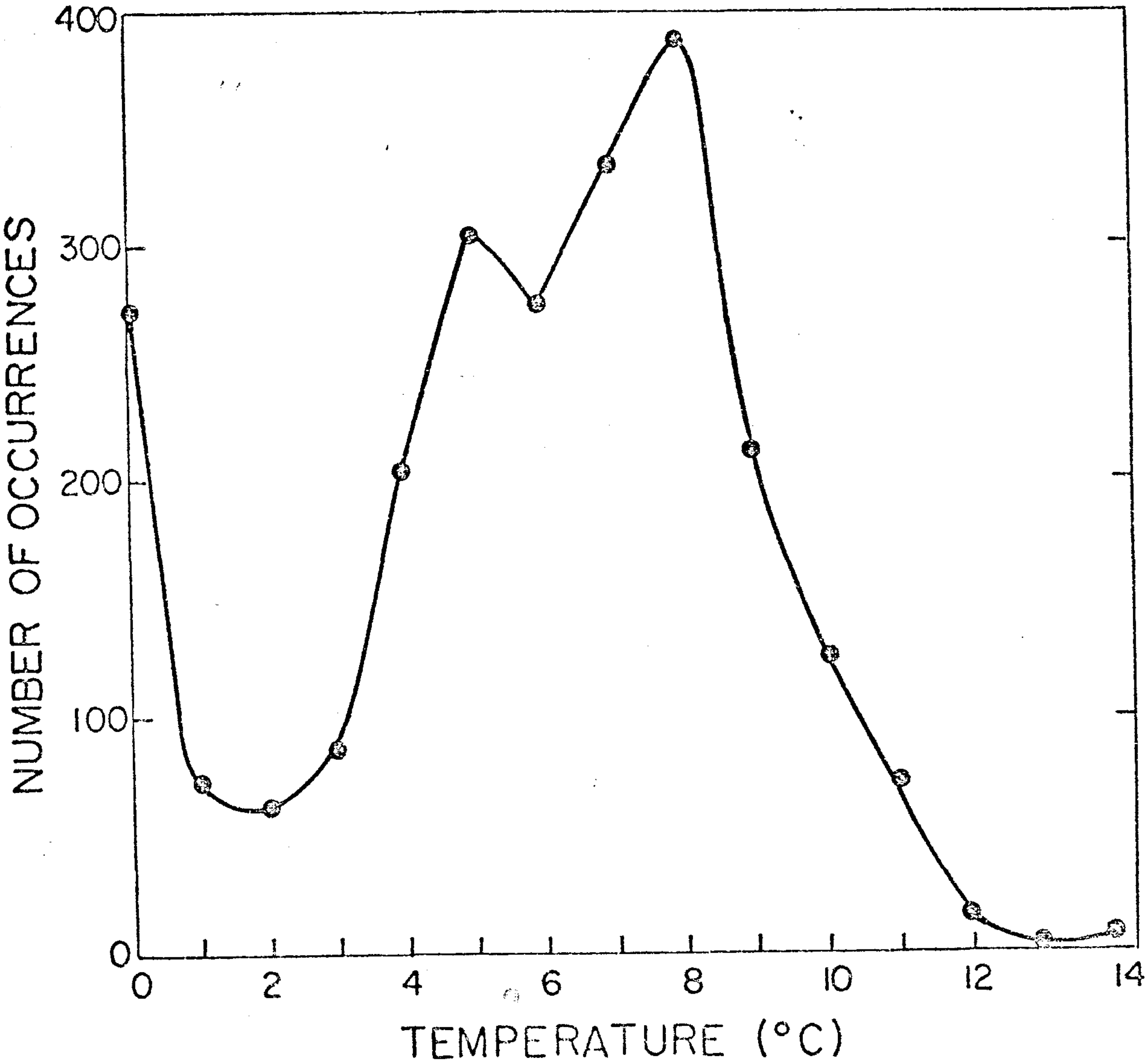
The perch overall winter temperature frequency distribution was found to be bimodel with peaks at $0^{\circ}C$ and $8^{\circ}C$ (Figure 28). The lower mode reflected the large number of temperature observations on fish that moved into unaltered waters. The $8^{\circ}C$ mode represented the most commonly encountered temperature while yellow perch were in the discharge affected areas. The mean overall temperature selection for yellow perch determined by averaging individual means was found to be $5.4^{\circ}C$.

A large number of winter perch temperature observations were collected from fish outside of the discharge area. Therefore, the overall winter temperature data did not reflect the temperature selection of perch in the discharge bay since, (Table 19) every fish resided in unaltered waters at least briefly. Yellow perch winter mean temperature selection in discharge affected areas was obtained by analyzing temperatures greater than $1^{\circ}C$, thus eliminating data from outside of the thermal plume.

Table 20. Overall yellow perch winter temperature selection grouped at the P = .05 level by various multiple comparison tests.

Least Significant Difference			Student-Newman Keuls			Scheffe		
Subset No.	Fish Id. No.	Mean	Subset No.	Fish Id. No.	Mean	Subset No.	Fish Id. No.	Mean
1	1843	1.1	1	1843	1.1	1	1843	1.1
							1844	2.4
2	1844	2.4	2	1844	2.4			
						2	1833	3.4
3	1833	3.4	3	1833	3.4		1838	4.8
							1834	5.0
4	1838	4.8	4	1838	4.8		1836	5.1
	1834	5.0		1834	5.0			
	1836	5.1		1836	5.1	3	1836	5.1
							1842	6.6
5	1842	6.6	5	1842	6.6			
						4	1837	7.4
6	1837	7.4	6	1837	7.4		1847	8.5
							1848	9.2
7	1847	8.5	7	1847	8.5			
	1848	9.2		1848	9.2			

Figure 28. Yellow perch overall winter temperature frequency.



400
300
200
100
0
NUMBER OF OCCURRENCES
0
2
4
6
8
10
12
14
TEMPERATURE (°C)

Table 21 presents discharge area winter perch temperature selection results. Variability among individual perch remained substantial. The multiple comparison test using the 'Scheffe' procedure separated the 10 individuals into 5 significantly ($P = .05$) different subsets (Table 22). The mean temperature selection for yellow perch in discharge affected areas determined by averaging individual means was found to be $6.3^{o}C$.

Because of the high degree of temperature variability among the individual perch, winter diel temperature selection was examined on an individual basis. Diurnal and nocturnal temperature data were analyzed for overall data and for the discharge area observations. Results are presented in Table 23. A t-test on overall individual perch winter day and night mean temperatures indicated no significant ($p = .05$) difference. However when the data were analyzed for perch only in discharge areas, 2 of 6 individuals preferred significantly warmer areas during the day with the diurnal means $0.7^{o}C$ and $0.6^{o}C$ higher for these two fish.

Summary

A high degree of variability was detected among individual perch with respect to temperature selection. In general, yellow perch selected relatively cool winter temperatures from the $0^{o}C$ to $15^{o}C$ gradient available. An overall winter mean of $5.4^{o}C$ was found for all data and a mean of $6.3^{o}C$ observed for fish in discharge affected areas. Yellow perch varied slightly but not significantly with respect to diel temperature selection.

Table 22. Yellow perch winter temperature selection in thermally altered areas.

Id.No.	No. of Observations	Mean	Standard Deviation	Minimum	Maximum	95% Confidence Interval
1833	74	4.5	2.0	1.1	9.3	4.0 - 5.0
1834	130	6.2	2.0	3.9	12.8	5.8 - 6.5
1836	18	6.5	1.4	4.1	8.6	5.7 - 6.5
1837	1096	7.5	2.0	1.2	13.0	7.4 - 7.6
1838	274	5.9	1.9	1.1	12.9	5.7 - 6.2
1842	343	6.8	2.4	1.4	14.4	6.5 - 7.1
1843	35	2.8	1.9	1.2	10.1	2.1 - 3.4
1844	28	3.2	2.5	1.2	8.8	2.3 - 4.2
1847	25	10.7	2.4	6.9	14.6	9.7 - 11.7

Total 2143

Mean by averaging individual means: 6.3

Mean by grouped data: 7.0

Table 22. Yellow perch winter temperature selection in thermally altered area grouped at the P = .05 level by analysis of variance.

Scheffe 'Procedure		
Subset No.	Fish Id. No.	Mean ^{o}C
1	1843	2.8
	1844	3.2
	1833	4.5
2	1833	4.5
	1838	5.9
	1834	6.2
	1836	6.5
3	1834	6.2
	1836	6.5
	1842	6.8
4	1836	6.5
	1842	6.8
	1837	7.5
	1848	8.6
5	1847	10.6

Table 23. Diel winter perch mean temperatures.

OVERALL					IN DISCHARGE				
Fish Id.No.	Diurnal Mean	Nocturnal Mean	Calculated Test Statistic	(P=.05) Critical Test Statistic	Fish Id.No.	Diurnal Mean	Nocturnal Mean	Calculated Test Statistic	(P=.05) Critical Test Statistic
1833	3.3	3.8	0.3	1.98	1833	4.6	4.3	0.8	1.99
1834	4.2	6.1	1.4	1.98	1834	6.0	6.3	0.9	1.98
1837	7.4	7.4	0.0	1.98	1837	7.6	7.4	0.9	1.98
1838	4.7	4.8	0.0	1.98	1838	6.3	5.6	3.1	1.98
1842	6.7	6.5	0.1	1.98	1842	7.1	6.5	2.3	1.98
1843	1.5	0.3	0.7	1.98					
1848	8.1	8.8	0.3	1.98	1848	8.1	8.9	1.89	1.98

AUTUMN DISTRIBUTION RESULTS

The high percentage of yellow perch observed dispersing from the discharge area during the late winter and early spring months resulted in an expansion of the project. I speculated they would return to thermally altered areas the following autumn as the river cooled, and the fish followed the thermal gradient to maintain temperatures closer to reported temperature preferenda. Fish approaching the discharge confluence with the river could react positively and move into the discharge bay. A negative reaction would be observed if the fish encountered the gradient and either turned back or continued moving through the periphery to thermally unaltered areas. Figure 29 presents average fall isotherms above ambient.

During the fall months of 1975 and 1976, fish were trapped and released in areas where radio tagged fish had dispersed to the previous spring. I tracked 62 yellow perch and 3 walleyes captured in areas upstream and downstream from the thermal discharge and 2 walleye from the discharge for a minimum of 7 days. Table 24 summarizes the results. Autumn tracking commenced in September 1975 when normal river temperature was 13°C and discharge temperature was 20°C. Tracking continued until December when normal river and discharge temperatures had dropped to 0°C and 10°C respectively. Nine yellow perch were tracked upstream from the discharge. Figure 30 depicts the distribution of daily locations of a typical 'upstream' perch. All individuals remained in waters under normal seasonal temperature conditions. Only one fish made a substantial move downstream toward the discharge area,

Figure 29.

Average fall isotherms above ambient. (Modified from MP & L, 1977 by permission.)

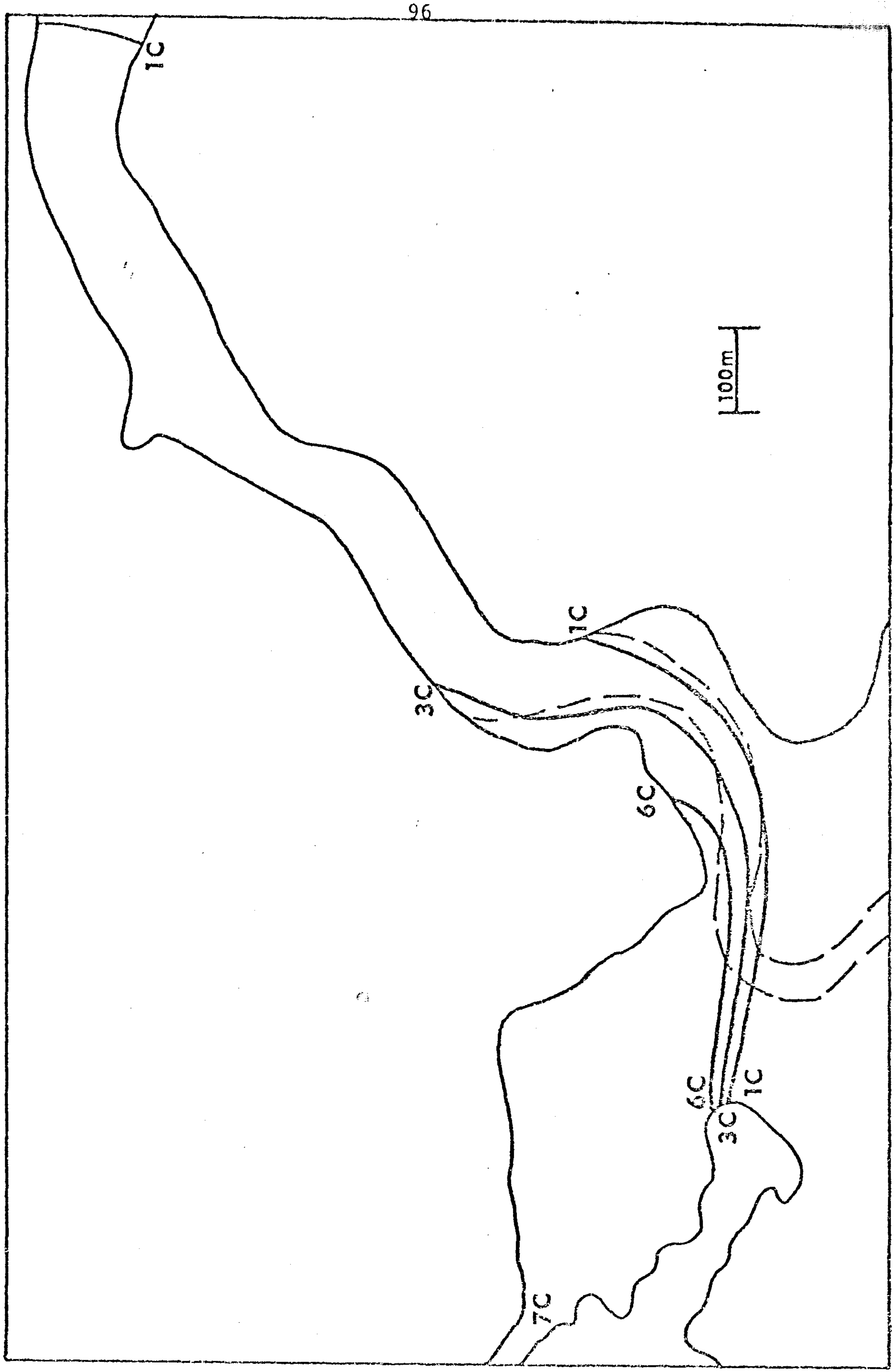
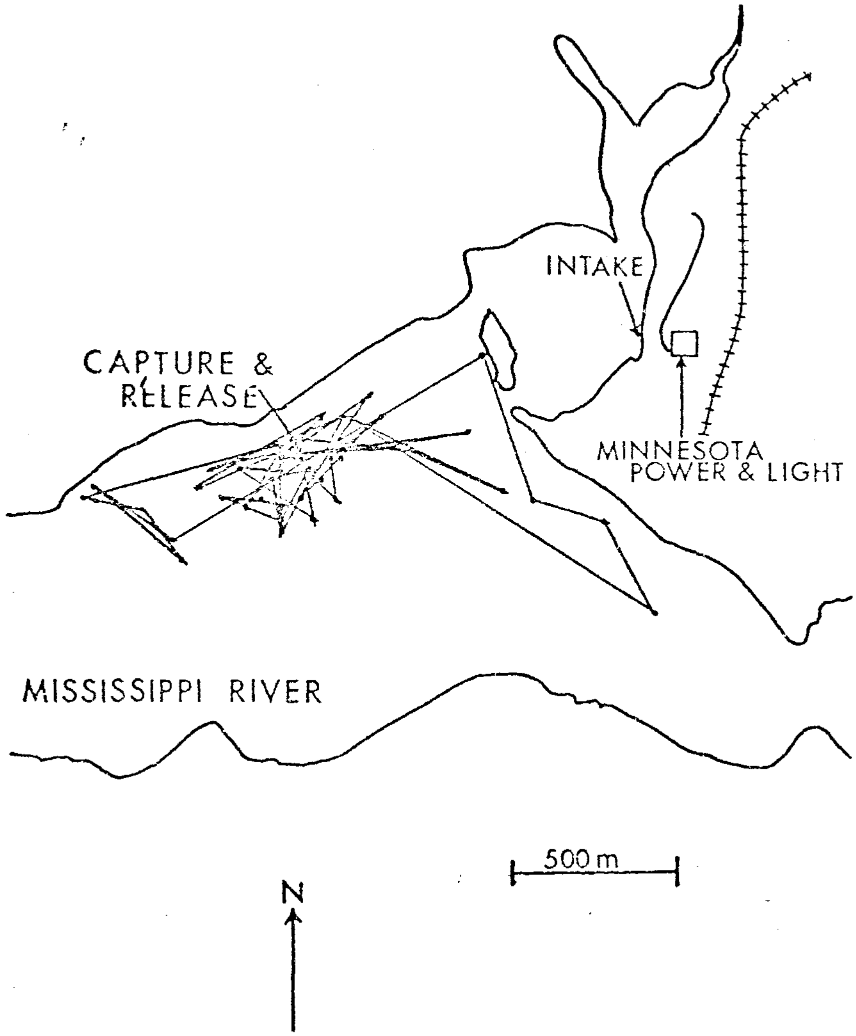

1C
100m
1C
3C
6C
6C
1C
3C
7C

Table 24. Autumn yellow perch movement.

	Fish tagged upstream from the discharge.					Fish tagged downstream from the discharge.				
	No. Tracked	No. moved toward discharge	Per-cent	No. moved into discharge	Per-cent	No. Tracked	No. moved toward discharge	Per-cent	No. moved into discharge	Per-cent
1975	9	1	11%	0	0%	5	3	60%	1	20%
1976						48	32	67%	1	2%
Total	9	1	11%	0	0%	53	35	66%	2	4%

Figure 30. Movement of perch no. 1813 from October 7, to November 19, 1975 as it remained upstream from the discharge area.

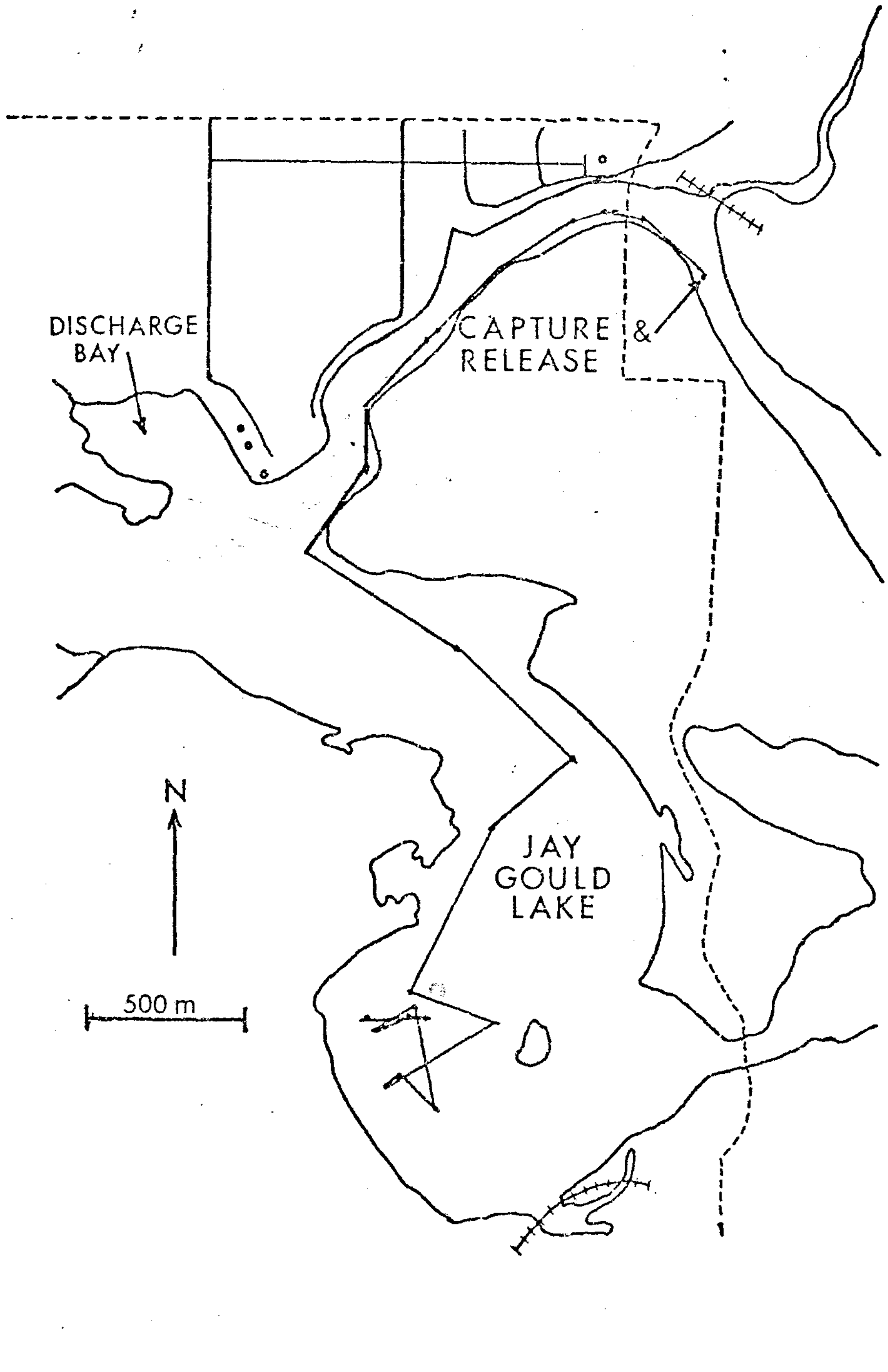

INTAKE
CAPTURE &
RELEASE
MINNESOTA
POWER & LIGHT
MISSISSIPPI RIVER
500 m
N

however, this perch moved into the thermally unaltered area of Jay Gould Lake. Three perch moved into the northwest bay of Blackwater Lake that supplies water to the intake of the power plant. The remaining 5 perch remained in shallow areas of Blackwater Lake upstream from the discharge.

Nine perch and 1 walleye were radio tagged downstream during the autumn of 1975. Figure 31 shows a typical location pattern of a 'downstream' perch. Initially fish trapping below the discharge and mixing zones was difficult due to strong currents and/or lack of knowledge of the area. Thus, 4 of 9 'downstream' perch were not radio tagged until November 27. By this time, normal river temperatures had cooled to $0^{\circ}C$. Discounting these last 4 perch, 3 of 5 perch moved through the mixing zone during the autumn cooling period. Two individuals subsequently moved into thermally unaltered areas of Jay Gould Lake. Only 1 individual continued to move up the gradient into the discharge area. This perch remained in the discharge area for a 5 day period after which it also moved into areas of Jay Gould Lake. Due to these unanticipated observations, I shifted all future autumn work downstream.

One walleye (no. 1814) which was radio tagged below the discharge moved upstream through the mixing zone and continued upstream 2.5 km beyond the confluence of discharge and river. This individual subsequently maintained a location centered around a 3.5 m deep bend in the meandering river channel between Blackwater and Cutoff Lakes. Two walleyes radio tagged in the discharge bay oscillated between the bay and thermally unaltered areas of Jay Gould Lake.

Figure 31. Movement of yellow perch no. 1813 from October 9 to November 1, 1975 as it moved upstream from below the mixing zone into Jay Gould Lake.

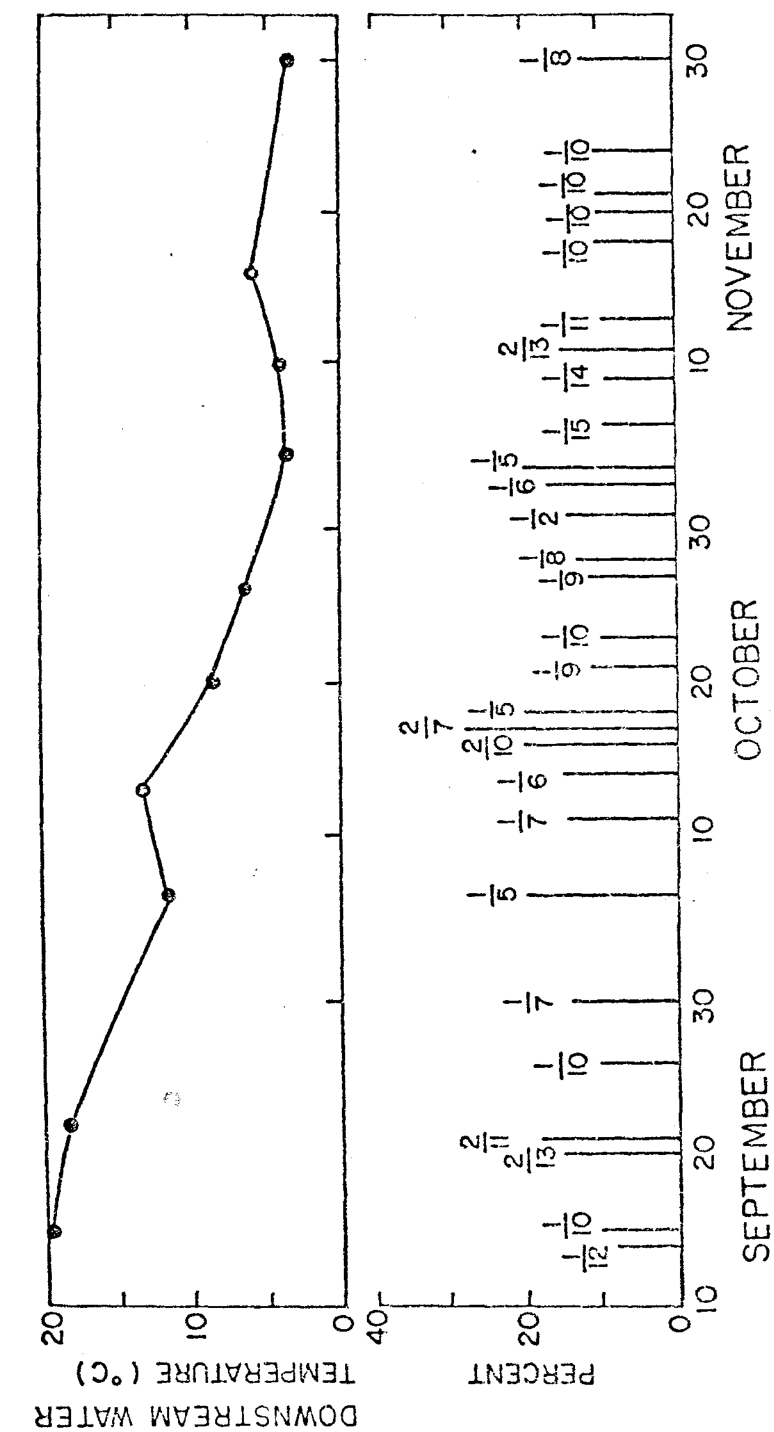

DISCHARGE
BAY
CAPTURE &
RELEASE
N
JAY
GOULD
LAKE
500 m

Fifty-six yellow perch and 2 walleyes were captured and radio tagged below the thermal discharge between September 10 and December 1, 1976. River temperatures dropped from 19°C to 3°C and discharge temperatures fell from 27°C to 12°C. Forty eight perch were tracked successfully. Six transmitters failed prematurely. Thirty-two of 48 perch moved upstream encountering the mixing zone. Only 1 fish visited the discharge bay for 1 day prior to moving into thermally unaltered areas of Jay Gould Lake. The remaining 31 individuals moved into thermally unmodified areas of Jay Gould Lake, Little Jay Gould Lake, Pokegama Lake and the river above the confluence with discharge waters or returned downstream below the mixing zone. Figure 32 depicts river temperature and the autumn 1976 perch movement upstream as a percent of the total number of perch transmitting downstream from the confluence of the discharge and Mississippi River on a given day. The greatest upstream movement occurred between October 13 and November 3, with a peak of 29% (2 of 7 individuals) occurring on October 16. At this time downstream river temperatures were dropping rapidly, relative to other autumn periods. The only perch that entered the discharge area during the fall of 1976 moved upstream into the discharge bay during this period.

Two autumn 1976 walleyes which were tagged below the discharge moved into the discharge bay within a day of release. Subsequently 1 of these fish moved between discharge and thermally unaltered areas. The other moved upstream to the same 3.5 m deep bend in the river channel that walleye no. 1814 had occupied the previous fall.

Figure 32. - Autumn 1976 Downstream River Temperature (degrees celsius)

- Autumn 1976 Yellow perch moving upstream as a percent of the total number of radio tagged perch monitored downstream from the discharge area each day.


DOWNSTREAM WATER TEMPERATURE (°C)
PERCENT
SEPTEMBER
OCTOBER
NOVEMBER

Summary

The results of 2 autumn seasons fish tracking outside of the thermal discharge bay indicated 35 of 53 perch tracked below the discharge moved upstream through the mixing zone. Only 2 of the 35 continued in a positive direction through the thermal gradient into the discharge bay. Further, these two perch remained in the thermally modified area only for a short period of time. None of the 9 perch tracked above the discharge - river confluence moved into thermally altered waters. Five walleyes tagged during the fall months appeared either to oscillate between discharge and thermally unaltered waters or to move upstream beyond the mixing zone.

4. ASSOCIATED OBSERVATIONS

Yellow Perch Length and Weight

Length and weight observations from yellow perch captured in commercial fishing operations between April 30 and May 5, 1975, are presented in Table 25. A t-test indicated neither standard length nor weight varied significantly between perch of the same sex captured in the discharge area vs the Mississippi River immediately upstream.

Gonado-Somatic Indices

Prespawning gonado-somatic indices of yellow perch captured between April 7, 1975 and May 5, 1975 were similar for fish collected in thermally modified and unmodified areas. Indices for 20 females from modified areas ranged from 2.8% to 26.3% with a mean of 17.7%. Indices for 27 females from unmodified areas ranged from 1.7% to

Table 25. Yellow perch standard length and weight observations, April 30, to May 5, 1975.

	Unmodified Areas				Thermally Altered Areas			
	Female		Male		Female		Male	
	Weight grams	Length cm.	Weight grams	Length cm.	Weight grams	Length cm.	Weight grams	Length cm.
Mean	299	21.9	197	19.6	289	22.3	176 g	19.3
No. Observations	77	76	23	25	36	35	19	22
Standard Deviation	87	2.0	64	1.8	77	2.0	62	1.9

23.3% with a mean of 16.8%. Similarly, indices for 13 males from modified areas ranged from 0.8% to 5.3% with a mean of 2.5% compared to a range of 0.4% to 3.7% and a mean of 1.9% for males from unheated waters. These figures compared closely to mean gonado-somatic indices of 16.2% for female and 3.9% for male perch obtained from Minnesota Department of Natural Resources traps at Little Cutfoot Sioux Lake on May 9, 1975. These perch were from a thermally unmodified area approximately 50 km north of the study area. Eighteen percent of females over 150 g from Little Cutfoot Sioux Lake were considered undeveloped. The ovary weight was less than 10% of the whole body weight. This compares to 20% undeveloped females from the discharge area and 14.8% undeveloped females from unaltered waters near the discharge.

Winter Trap Netting

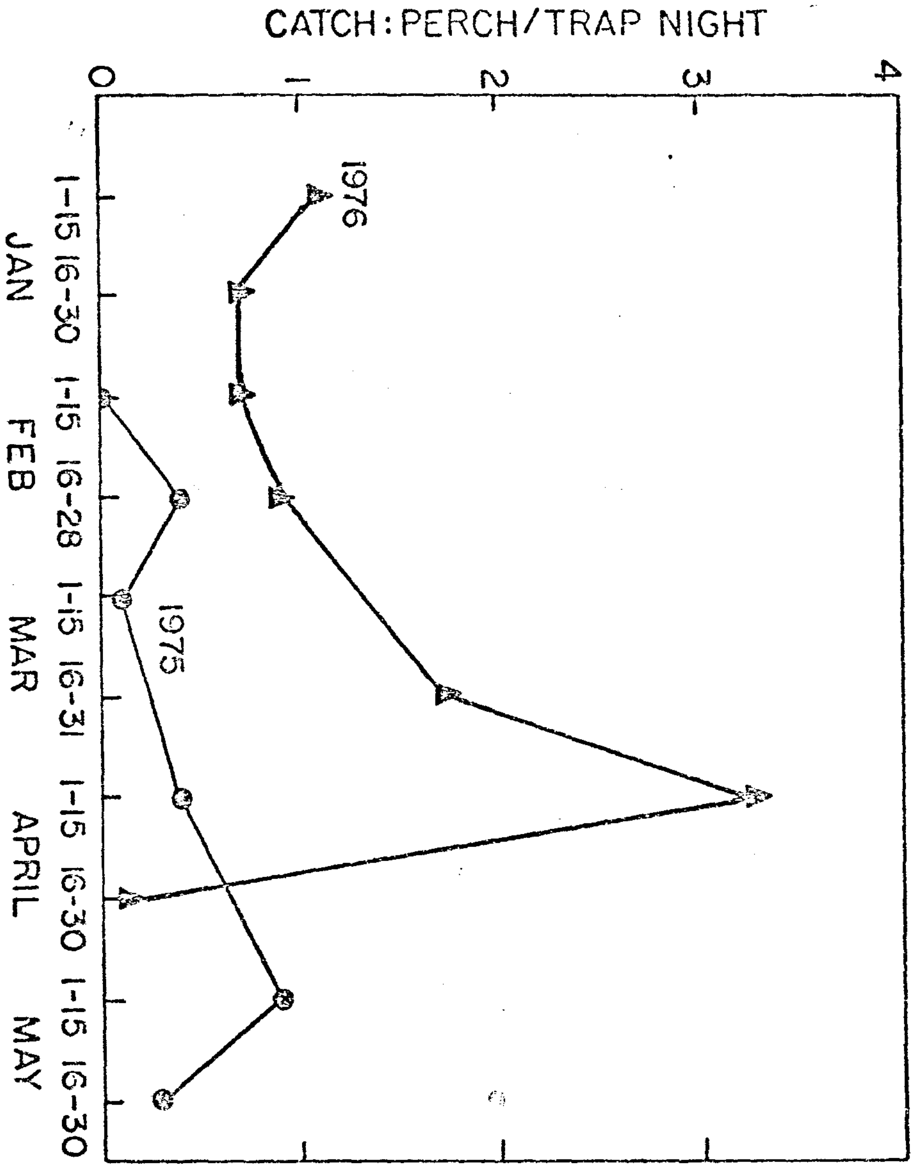
Winter trap netting catch rates for the discharge bay are presented in Table 26. Bullheads, rockbass, dogfish and bluegill sunfish were the most commonly encountered species. Walleye, largemouth bass, white fish, tullibee and burbot were among the least frequently encountered. Dogfish and bluegill trapping rates dropped substantially from 1975 to 1976 while yellow perch and rock bass rates increased.

Winter and spring yellow perch catch rates in the discharge area are plotted in Figure 33. Catch per trap-night increased in 1976. However, catch rates peaked both years near the spawning season.

Table 26. Winter 1975 and 1976 catch rates for the discharge area.

	Trap/Nights	Dog fish	Bullheads	Common White Sucker	Northern Pike	Walleye	Yellow Perch	Largemouth Bass	Rockbass	Bluegill Sunfish	Pumkinseed Sunfish	Crappie	Tullibee	Whitefish	Burbot
Winter 1975 Totals	90	450	2043	18	29	3	25	7	91	227	22	19	1	3	0
Winter 1975, Catch/Trap night:		5.0	22.7	0.2	0.3	0.03	0.3	0.08	1	2.5	0.24	0.21	0.01	0.03	0
Winter 1976 Total:	249	199	4399	13	103	4	248	1	577	78	41	41	0	3	2
Winter 1975, Catch/Trap night:		0.8	17.6	0.05	0.4	0.2	1.0	0	2.2	0.3	0.2	0.2	0	0.01	0.01

Figure 33. Yellow perch catch per trap night in discharge area for 1975 and 1976.


CATCH: PERCH/TRAP NIGHT
0
1
2
3
4
1976
1975
1-15 16-30
JAN
1-15 16-28
FEB
1-15 16-31
MAR
1-15 16-30
APRIL
1-15 16-30
MAY

Spawning Condition and Sex Ratios

Figure 34 presents spawning condition and sex ratios of yellow perch collected by commercial fishermen from discharge and unmodified areas in 1975. Data from natural areas were available only after the ice was out. A high percent of discharge area males were ripe over the entire spawning period. Females were generally green before April 30. Changes in sex ratios indicated that males moved into spawning areas in the discharge by April 21, followed shortly thereafter by females. The peak of spawning occurred between April 30 and shortly after May 5, 1975 in both discharge and unmodified areas. Similar data were not available for 1976; however, by April 20, 15 of 19 female perch collected by electrofishing in both modified and unaltered areas were spent. Also after April 19 catch rates in discharge area nets dropped to 0.1 perch/trap-night. They had averaged 3.3 from April 1 to 6, 1976. For the same time intervals, catch rates in unaltered areas climbed from 6 to 9.4 perch/trap-night, apparently indicating that perch were leaving the discharge area for unaltered water.

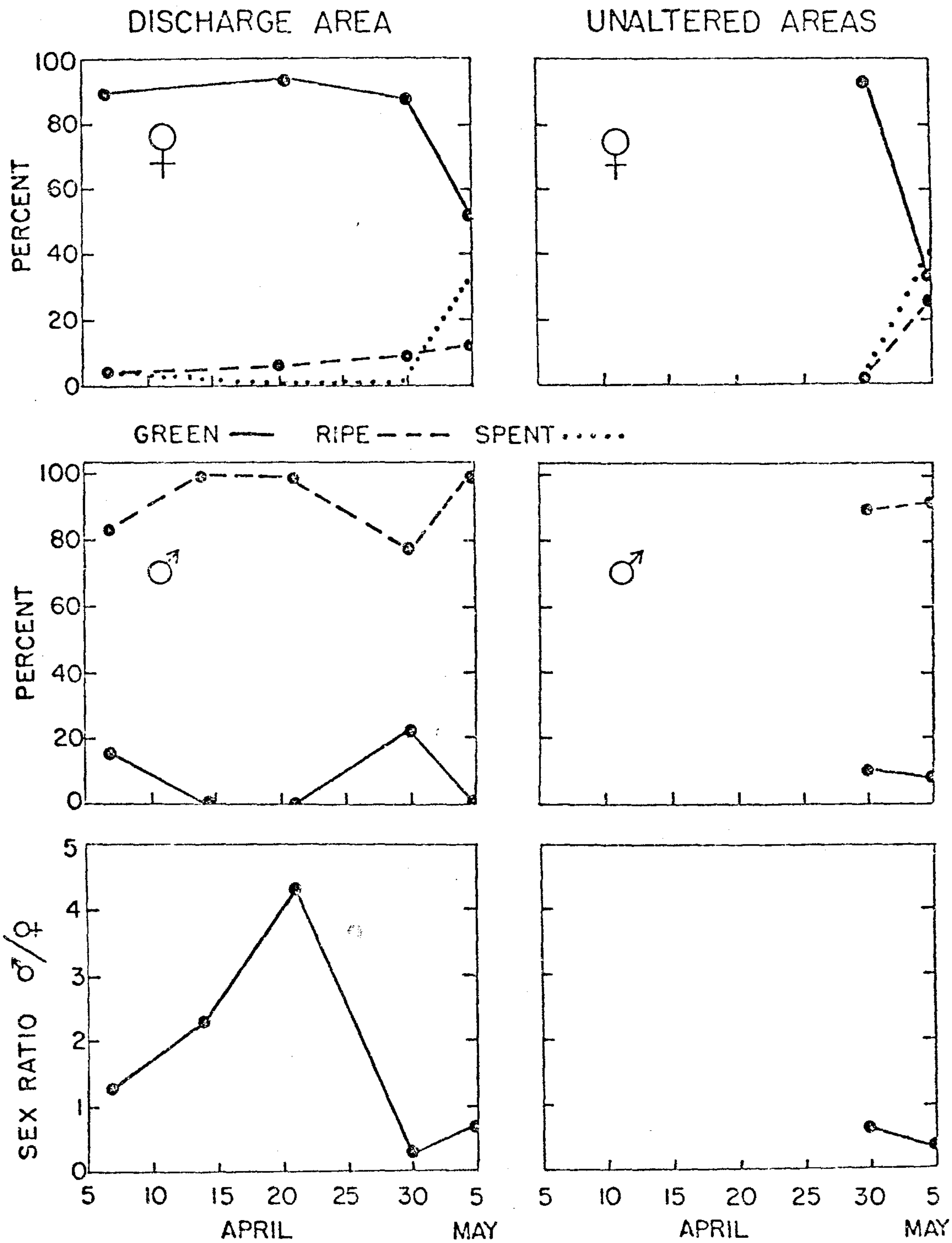
Recaptures

The recapture of both radio and Atkins tagged fish provided valuable information (Table 27). Recapture rates for radio tagged fish were similar to Atkins tagged individuals. Nine radio tagged yellow perch recaptured in nets had an average of 11 other perch of various sizes in the same net. Recaptured radio transmitter tagged perch were in good condition with no debris or vegetation entangled with the transmitter. Transmitter and backing washers generally

Figure 34. - Spawning condition of yellow perch females from discharge and unaltered areas.

- Spawning condition of yellow perch males from discharge and unaltered areas.

- Sex ratios of yellow perch from discharge and unaltered areas.



DISCHARGE AREA
UNALTERED AREAS
100
80
60
40
20
0
PERCENT
♀
GREEN
RIPE
SPENT
♂
SEX RATIO ♂/♀
5
4
3
2
1
5
10
15
20
25
30
APRIL
MAY

Table 27. Yellow perch recapture data.

	No. Tagged	RETURNS			
		Netting	Electro-fishing	Angling	Total Percent Return
RADIO	116	9	1	1	9.5 %
ATKINS	903	61	3	5	7.7 %

remained firmly attached and little, if any, abrasion was noted around the transmitter or attachment washer. One female tagged prior to spawning and recaptured 45 days later had released its eggs. The peak of spawning also occurred during this time period. A radio tagged walleye recaptured after 166 days had abrasions and lesions near the anterior end of the attachment backing washer. A radio tagged northern pike recaptured 11 months after tagging appeared to be in good condition. The skin under both the transmitter and attachment backing washer had abrasions, but there was no obvious infection. This 5.67 kg. female had maintained its weight over the 11 month period.

While trapping downstream from the mixing zone during the fall of 1976 a yellow perch Atkins tagged in the discharge bay the previous winter was collected.

Angler returns of Atkins tagged fish provided insight into long term movement. A yellow perch tagged in the discharge bay December 10, 1975 was caught 7.2 km upstream in the Mississippi River during the summer of 1976. Another perch tagged 0.8 km above the discharge on May 3, 1975 was caught June 24, 1976 6.2 km further upstream. A yellow perch tagged April 21, 1975 in the discharge bay was caught 6 km downstream below the Pokagana Dam on June 18, 1975. Angler returns of two walleyes showed even further long term movement. A 312 g walleye tagged 0.8 km above the discharge on May 3, 1975 was caught approximately 16 km further upstream on October 12, 1975. A 1.59 kg walleye tagged December 2, 1975 in the discharge bay was caught 7.2 km downstream, below the Pokegama Dam on July 9, 1976.

DISCUSSION

Habitat selection is a complex and dynamic process. The habitat a fish selects is probably influenced by many variables including light, temperature, depth, ice cover, dissolved and suspended chemicals, vegetation, predators, prey and competition. Furthermore, the relative importance of each parameter may vary with species, time of day, weather patterns, season, and environmental alterations. This study evaluated the comparative impact of an industrial perturbation on the habitat selection of four fish species as determined by distribution and temperature selection.

The telemetry results indicated that each species reacted differently in a thermal discharge. With the exception of largemouth bass, the thermal experience appeared to be transitory in nature. Temperature most likely played a relatively minor role in the autumn, winter and early spring habitat selection of yellow perch and winter habitat selection of northern pike. Additionally, observations on recaptured animals suggested that neither radio tagging nor handling adversely affected behavior or survival.

The nature of telemetry studies limits researchers to making numerous observations on relatively few animals. An implicit assumption is that tagged animals behave similarly to the remainder of the population. Our recapture rates of radio tagged yellow perch compared with those of Atkins tagged perch indicated that activity and survival of radio tagged fish were similar to perch marked with standard fisheries methods. Due to minimum size limitations of the radio transmitter, we usually tagged large perch that were almost always female. However, the fact that an average of 11 other yellow perch of various sizes were in the same net with 9 recaptured perch suggested that large radio tagged females were not segregated from the other portions of the yellow perch population. Finally, observations on recaptured fish indicated that radio tagged fish suffered limited physical injury due to externally applied radio transmitters. Although limited data are available, in general it appears that properly applied small radio transmitters do not interfere with short term fish behavior of the nature involved in this study.

My observations that largemouth bass had a small home range entirely within the discharge area in shallow relatively warm water compare favorably with those in the literature. Winter (1977) determined that 95% of the largemouth bass locations were within 100 m of the geometric center of activity; additionally, 94.2% of the locations were less than 3 m deep during the summer in an unaltered Minnesota lake. Relative to yellow perch and walleye, largemouth bass were reported to have the highest final temperature preferendum (Coutant, 1975). Clugston (1973) found largemouth bass rotating in and out of a thermal discharge; however, minimum ambient water temperature in his study area ($11 \pm 2^{o}C$) was considerably warmer than the $0^{o}C$ temperatures occuring outside of the Clay Boswell discharge area. Largemouth bass movements rates reported by Clugston (1973) and Peterson (1976) were higher than the winter rates we found, but, our determinations were a minimum daily rate because fish were not tracked continuously.

Walleyes tagged in the thermal discharge were found either to confine most of their winter movements to the deeper cooler areas of the discharge or to leave discharge areas shortly after tagging. Little data exist in the literature concerning the effect of thermal discharges on walleye behavior. However, Holt et al. (1977) found that the mean depth in which walleyes were found in an unaltered lake was 2.8 to 7.2 m. This agrees well with the depth selection of the only walleye we monitored in the discharge areas for an extended period. Both localized short term activity (Kelso 1976a) and rapid movement between areas (Bahr 1977) have been observed for walleyes. Perhaps the relatively small amount of area greater than 3 m deep in the discharge bay limited the number of walleyes that remained in the discharge bay during winter months. These fish exhibited localized activity confined to the center, deeper areas. Other walleyes left the discharge area rapidly for thermally unaltered waters.

Apparently temperature preference did not sufficiently influence habitat selection in the 5 walleyes tracked during autumn months. Individuals oscillated between altered and unaltered waters. The only site specificity observed was a large bend in the meandering river channel approximately 2.5 km above the discharge confluence with the river.

As with walleyes, little information is available concerning northern pike behavior near thermal discharges. However, the relatively high amount of movement, large home range and shallow depth selection of northern pike agree with the winter observations of Diana et al. (1977) for a thermally unmodified area. They noted that pike were generally found in near shore areas less than 4 m deep. Also, this species did not develop a well defined home range; daily movements ranged from 0 to 4000 m. and 70% were more than 200 meters.

Yellow perch behavior relative to thermal discharges has been studied more extensively. Our observations concur with those of Storr and Schlenker (1973) and Kelso (1976b). In general,the thermal discharge had little long term effect on the behavior and distribution of yellow perch. Perhaps the key to this conclusion was the high degree of variability noted among individual yellow perch with respect to winter temperature selection. However, many other observations supported this hypothesis. The low overall winter temperature preference, high amounts of movement between thermally altered and unaltered areas, the transitory nature of thermal experience and the failure of yellow perch to ascend an autumn temperature gradient were all behavioral indications that factors other than temperature preference contributed significantly to habitat selection. Similar physiological observations on perch from altered and unaltered areas with respect to length, weight, spawning condition and timing suggested that thermal effects, if any, were limited.

The scope of this investigation was confined to thermal effects. However, telemetry, trapping and field observations can potentially elucidate environmental factors other than temperature to more fully explain the observed distribution of yellow perch. Trapping data indicated high numbers of ictalurids, centrarchids, and dogfish in the discharge bay. Perhaps competition from these more thermophilic species accounted for the lack of positive thermal response observed in yellow perch. Secondly, perch may have preferred the comparative darkness offered by ice cover during winter months when vegetation cover was at a minimum. Telemetry data indicated that northern pike, as visual feeder and major predator on yellow perch preferred the same generally shallow areas away from the discharge point where perch were most often located when in discharge areas. Spring trapping data suggested that perch moved into the relatively higher standing stock of aquatic vegetation to spawn in the discharge bay. Both trapping and telemetry observations indicated that a high percentage of these fish subsequently dispersed shortly after spawning. The observed autumn distribution and movement patterns could have been a response to the aquatic vegetation dying and washing away in the narrow channel downstream from the confluence with the thermal discharge. Perch situated upstream from the discharge did not encounter as severe a loss of habitat because this area was characteristically a wide shallow environment where the river channel meandered through wild rice beds.

Behavior with respect to food and water chemistry was not evaluated. No data were gathered relative to the abundance of food organisms. While a good deal of literature is available concerning toxicity of various levels of chemicals on growth and survival, little is known of the chemical effects on fish behavior. Furthermore, a real paucity of information exists relative to the synergistic effects of temperature and various water chemistry parameters on fish behavior. Therefore, the chance that power plant induced alterations in water chemistry could account for the lack of positive thermal response remains a possibility until further research is performed.

In summary, thermal effects appeared to restrict walleye movement in the discharge area and maintained conditions in shallow areas preferred by largemouth bass. Northern pike movement was not limited to nor specific for any portion of the discharge area. On a relative basis, movement patterns of largemouth bass, walleye and northern pike were not substantially altered from those reported in the literature from thermally unaltered areas. Finally, the results indicated that an elevated temperature in conjunction with the numerous other environmental variables in a dynamic river system did not alter the distribution of yellow perch as would be predicted on the basis of laboratory temperature preference experiments. Interpretation of cause and effect data gathered independently are difficult; however, environmental factors such as competition, predation and the dynamics of suitable aquatic vegetation habitat could more fully account for the observed fall, winter, and early spring distribution of yellow perch.

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